OLUME 46 NUMBER 3

TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

September, 1941

Founded by LOUIS A. BAUER
Conducted by J. A. FLEMING
With the Cooperation of Eminent Investigators

CONTENTS

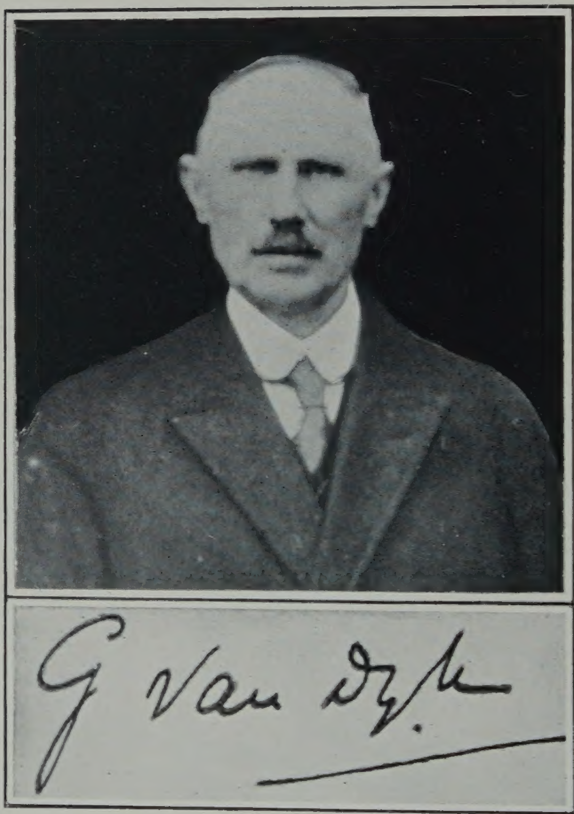
(*Contents concluded over*)

PUBLISHED FOR
THE JOHNS HOPKINS PRESS, BALTIMORE, MARYLAND
THE RUTER PRESS, 420 PLUM ST., CINCINNATI, OHIO
THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR

THE JOHNS HOPKINS PRESS
BALTIMORE, MARYLAND
Entered as second-class matter at the Post-office at Cincinnati, Ohio

CONTENTS—Concluded

[Plate 2]



Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME 46 SEPTEMBER, 1941 No. 3

DIRECTIONAL AND DIURNAL CHARACTERISTICS OF AURORAS AT SOME PLACES IN CANADA

BY B. W. CURRIE AND C. K. JONES

Introduction—Observations of auroras at almost all places on the Earth's surface indicate that displays extend along some predominating horizontal direction and that the maximum diurnal activity occurs at a particular time, both of which are typical of the locality in question. Vegard [see 1 of "References" at end of paper] has shown that the average directions of arcs and bands at a number of the places in the Northern Hemisphere are systematized and assume added significance if they are referred to the geomagnetic rather than to the astronomical meridians. In most cases the average angle between the westward-directed end of the arcs and bands observed at a particular place and the geomagnetic meridian through the place is several degrees greater than 90°. Vegard [1, 2] has examined also the diurnal frequency of auroras for a number of northern stations, and has expressed the opinion that within the limit of error the principal maximum occurs at about one hour before geomagnetic midnight. On the other hand Hulburt [3] from the data of many arctic and antarctic expeditions suggests that the diurnal course of an auroral display is dependent upon the meteorology of the upper atmosphere at a station.

In addition to their inherent value in describing auroral phenomena, the directional and the diurnal characteristics of auroras are of considerable interest in studies of geomagnetic disturbances. The association of magnetic storms with wide-spread auroral displays has been a long-established fact, although attempts to relate the observed variations of the magnetic elements with coincident features of auroral displays have not been particularly successful. Birkeland [4], Chapman [5], McNish [6], Vestine [7], Vestine and Chapman [8], and others have shown that many of the characteristics of magnetic storms in polar latitudes can be explained conveniently by postulating electric currents flowing in the atmosphere at heights common to auroral phenomena and in directions (for the Northern Hemisphere at least) approximately paralleling the curve of annual maximum auroral frequency as given by Fritz.

If these currents do exist, then their distribution in the atmosphere should be affected by the variation of ionization at times of auroral activity. Vestine and Chapman [8] have shown that the direction of flow of linear electric currents computed for several of the disturbances of the Earth's magnetic field, referred to as bays, is approximately parallel

to the positions of quiescent homogeneous auroral arcs for the region in question; and that their lateral positions vary from time to time, to north and to south of the zone of annual maximum auroral frequency. Stagg and Paton [9] from an analysis of simultaneous auroral and geomagnetic events at Fort Rae, during the Second International Polar Year, found that the location of a concentrated linear current, to which was attributed the simultaneous changes in the horizontal and vertical components of the magnetic field, was on the same side of the magnetic vertical plane as coincident auroral arcs five times as frequently as on the opposite side.

Observations of auroras made at a number of places in Canada as part of Canada's contribution to the Second International Polar Year are used in this study. The most extensive observations were made at Chesterfield (63°.3 north, 90°.7 west), Cape Hope's Advance (61°.1 north, 69°.6 west), and Coppermine (67°.8 north, 115°.2 west). Numerous single-station photographs and visual observations for the period from October, 1932, to August, 1933, were made at the first-named place; in addition double-station photographs for short periods in January, February, and March, 1933, were taken. From the other two places single-station photographs and visual observations covering approximately the same period of observation as at Chesterfield were at our disposal. The number of useful photographs from Coppermine was limited apparently because of a characteristic tendency of aurora at this station to be diffuse and to change rapidly in type and position. The observations from Cape Hope's Advance seldom included the early morning hours because of a lack of personnel. In addition, double-station photographs made at Saskatoon (52°.1 north, 106°.6 west) were available. While many of the pairs made at Saskatoon had been found to be useless previously for determinations of height [10], the individual photographs were suitable for the purposes of this study. Of the many available observations from other places only those from Aroostook (46°.8 north, 67°.7 west) were sufficiently detailed for reliable determinations of direction.

Procedure for determining directional characteristics—The most accurate information about the position in space of an auroral form can be obtained only from simultaneous double-station photographs. Measurements on a particular set of photographs will give the azimuths, the altitudes, and the lengths of straight lines from the principal photographic station to any number of selected points on the auroral form. From these quantities the heights above the Earth's surface and the locations of the vertical projections on the Earth's surface of the selected points can be computed. For a series of points along the lower edge of any portion of a relatively inactive arc or band within the angular field of the camera lens the heights are, as a rule, constant to within the limit of error of the measurements, and the projected points lie along a smooth curve that approximates closely to a straight line.[1] This curve gives the direction of this particular section of the arc or band.

From single-station photographs only the azimuths and altitudes of points on the auroral form can be obtained. Since the height of the lower edge of a quiet arc or band may be considered constant, an assumed

[1] For example, see "Report on aurora at Chesterfield, Canadian Polar Year Expeditions 1932-33," 2 (1939).

value for it makes possible the location of the projected points, and hence the direction of the arc or band. For any case where the height is not constant the projected points (except in very rare cases) do not lie along a smooth curve and the particular photograph can be discarded for the purpose of determining directions. Successful application of this method has been made previously by Sverdrup [11] using photographs taken on the *Maud* Expedition of 1918-25.

The actual measurements on the single-station photographs were facilitated by employing most of the methods developed by Störmer [12] and Vegard and Krogness [13] for determining the height of auroras from double-station photographs. The "nets," which are an essential part of these methods, were available for the photographs taken at Chesterfield and Saskatoon. In addition it was found that the Chesterfield "nets" could be used with the photographs taken at Coppermine and Cape Hope's Advance since the distortions introduced by the camera lenses used at the three places were practically the same. Essentially the same procedure as for measurements of height was followed until the azimuths and altitudes of a number of points along the lower edge of each arc or band had been found. The distances along the Earth's surface from the photographic station to each of the projected points were found graphically by the method described in detail on pages 28-29 of reference [13]. For all cases a height of 100 km was assumed. This value is approximately equal to the average lower limit of the height of arcs and bands at Chesterfield [14]. In any case the assumed value affects only the position and not the direction of the line through the projected points.

A graphical method was employed to find the direction of the projected lines. The region surrounding each station was mapped according to an azimuthal equidistant projection, the pole of the projection being located at the station. On these maps were plotted the geomagnetic lines of longitude and latitude at one-degree intervals. By this means the projected auroral points could be placed quickly on the map, a smooth line drawn through them, and the angle measured between the westward-directed end of this line and the geomagnetic meridian through its midpoint. This method also gave the approximate geomagnetic coordinates of the section of the arc or band under examination.

In order to get reasonably accurate results only photographs of arcs and bands with well-defined lower edges were selected. Two typical examples are shown in Figure 1. Again, if the projected arc or band did not approximate closely to a straight line, the photograph was discarded. Actually not more than about six per cent of the photographs meeting the first requirement had to be discarded because of their failure to satisfy the second.

For Aroostook, where visual observations were used to determine the direction of quiet arcs and bands, an arc or band was assumed to be perpendicular to the direction from the station to the point on the lower edge with the greatest altitude. Tests of this assumption by examining photographs from the other stations showed that it is in general correct.

Since quiet arcs and bands constitute only a small part of the total auroral disturbance at high-latitude stations attempts were made to determine the average direction of auroral displays at Chesterfield, Coppermine, and Cape Hope's Advance by using the visual records. Only displays crossing from horizon to horizon and reaching roughly

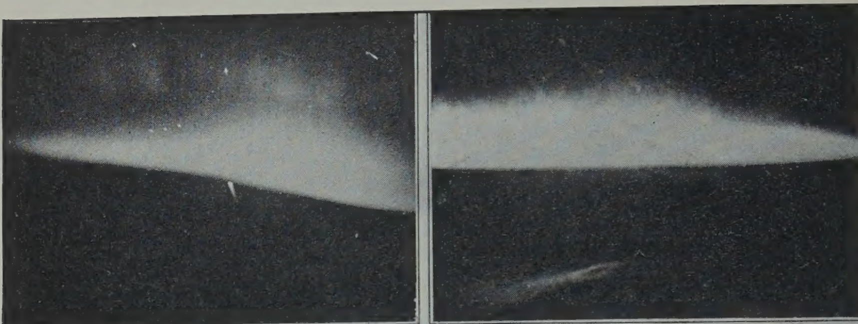


FIG. 1—PHOTOGRAPHS OF TYPICAL AURORAL FORMS USED IN COMPUTING DIRECTION OF QUIET ARCS AND BANDS

altitudes of 15° to 20° or more at their nearest position to the station were considered. The direction of the display was obtained in the same way as for the arcs and bands at Aroostook except when they passed close to or through the zenith. The latter cases, since the directions followed directly from the observations, were given twice the weight of the others. Although much of the observational data consisted of estimates by eye of direction to the nearest sixteenth point of the compass and, although the method of getting a direction had none of the precision involved in the use of the photographs, the very complexity of the auroral displays makes it unlikely that far more elaborate observational and analytical procedures would have led to more reliable results.

In order to analyze and to discuss the angular values for each station it was decided to treat them as random samples of a "parent population" in the statistical sense. The fact that the observational data included only a very small portion of all homogeneous arcs and bands occurring at the stations and that the angular values showed a very considerable scatter made other treatments of doubtful value. Incidental to this method of analysis the frequency-distributions of the angular values for Chesterfield and Cape Hope's Advance were tested for a Gaussian or normal distribution. Further discussion of this part of the work is given in the next section.

Results—The mean angular values of the directions of arcs and bands for the various stations are listed in Table 1. In addition the geomagnetic latitude (Φ) and longitude (Ω), the number of measurements, and the standard error are given for each place.

Table 1

Station	Φ	Ω	Angle	Variates	Standard error
	°	°	°		°
Chesterfield	73.5N	35.6W	105.2	231	1.39
Cape Hope's Advance	72.6N	0.9W	89.8	190	1.37
Coppermine	73.7N	75.5W	118.9	90	1.90
Saskatoon	60.5N	49.6W	113.2	54	2.34
Aroostook	58.3N	1.6E	84.9	39	1.62

An examination of the tabulated quantities shows a considerable variation of the means, and a very considerable scatter in the individual values used to compute the means since the standard errors are large for the numbers of measurements that are involved. Except for Coppermine and Saskatoon the differences between the means are apparently real and not the result of a lack of sufficient measurements, since the ratio of the differences between any pair of means to the square root of the sum of the squares of the corresponding standard errors is greater than 2, indicating that differences of this magnitude would occur less than five times out of a hundred through random sampling. Since the application of this test for significance of the difference between means presupposes not too great an abnormality in the parent populations, the measurements from Chesterfield and Cape Hope's Advance were tested for normality of distribution. The beta-coefficients (Pearson, "Tables for statisticians and biometricians," Part I) were computed. Their values are as follows: Chesterfield, $\beta_1=0.0031$ and $\beta_2=2.55$; and Cape Hope's Advance, $\beta_1=0.084$ and $\beta_2=2.50$. From these values it can be seen that the frequency-curve for each place is very symmetrical about the mean, and is somewhat flatter than the normal frequency-curve. In this connection it should be mentioned that the various measurements are independent of each other, successive photographs of the same arc or band and photographs of other parts of a particular arc or band being excluded. On the other hand the measurements cannot be considered as entirely representative of all auroras occurring at the two stations since the majority of them are for winter months when cloud-conditions were most favorable for auroral photography and for the hours before midnight when personnel was available. Further discussion will show that there are indications of seasonal diurnal, and longitudinal variations of direction. These may be responsible for the flattening of the frequency-curves, the observed distributions being composites of a number of normal frequency-distributions. In any case the observed distributions are not sufficiently abnormal to invalidate the aforementioned test.

The variations of the mean directions with geomagnetic latitude and longitude are shown in Figure 2, an azimuthal equidistant projection of the northern part of the Continent with the pole of the projection at the geomagnetic pole. The coastal outlines shown on this map must be considered only as a diagrammatic representation. For purposes of comparison the directions of arcs and bands given by Vegard [2] for Godthaab (64°.2 north, 51°.7 west), Nain (55°.6 north, 61°.7 west), Kingua Fjord (66°.6 north, 67°.4 west), Fort Rae (62°.7 north, 115°.7 west), Point Barrow (71°.4 north, 156°.7 west), Gjöahavn (68°.6 north, 95°.8 west), and King Point (69°.1 north, 138°.1 west) are shown. Also a value for Coral Rapids (50°.2 north, 81°.7 west), as deduced from a number of projected arcs and bands shown on Map 1 of reference [15], is included. Since these values for all except the last-mentioned place were computed from visual data they are probably not as reliable as those based on photographic data. The most noteworthy features are the apparent increase of the mean angular direction with increasing geomagnetic longitude measured westward, and the lack of any consistent variation with latitude. A critical test of the former observation should be possible when the analysis of the auroral photographs made at Fort

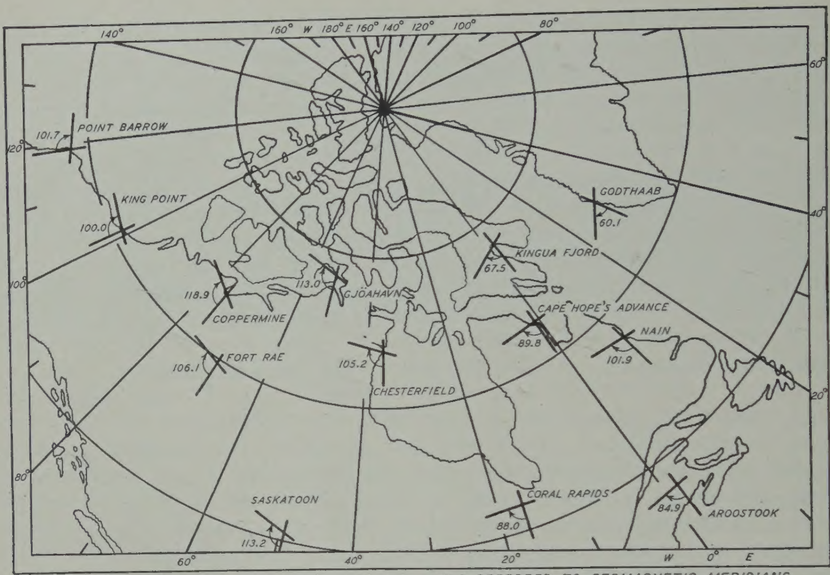


FIG. 2—AVERAGE DIRECTIONS OF QUIET ARCS AND BANDS REFERRED TO GEOMAGNETIC MERIDIANS

Rae by the party of the British Second International Polar Year becomes available.

The average angular directions of all extensive auroral displays computed from the visual observations made at Chesterfield, Cape Hope's Advance, and Coppermine are 98°.3, 88°.9, and 95°.3, respectively. The smaller angular values for the active displays in comparison with the angular values for the quiet arcs and bands in each case should be noted. Whether or not there is a real tendency for active displays to parallel the lines of geomagnetic latitude cannot be said with certainty. On the basis of the available data the decreases are statistically significant except at Cape Hope's Advance. At Chesterfield a direction cross was not used in making estimates of direction. Although the observational data for Coppermine and Cape Hope's Advance are reported mostly in degrees, a great tendency for the values to group into values corresponding to the first eight points of the compass suggests that they are eye estimates rather than measurements with the theodolite.

The directional values from the photographic observations at the three principal stations were examined for variations with respect to both geomagnetic longitude and latitude. A geomagnetic meridian was selected for each place so that the data were divided approximately into two groups, one group having the centers of the projected parts of the arcs and bands west and the other part east of the selected meridian. A similar procedure was followed for latitudinal variations. Significant increases in the angular directions were found to the west of Chesterfield and Cape Hope's Advance. No significant change of direction with latitude was found for any one of the three stations. Some increase to the westward of both Cape Hope's Advance and Chesterfield is to be anticipated from the previously deduced increase of angular direction with westward-measured longitude in the region occupied by these sta-

tions. The lack of a significant difference at Coppermine may indicate that Coppermine is located in a region where the angular direction has become stationary before decreasing to the lower values of King Point and Point Barrow.

Both the photographic and visual data for the three principal stations were examined for seasonal and diurnal variations. A minimum value of the angular direction during December and January is indicated by the monthly means for each place. However, the existence of this minimum could not be established statistically for the stations separately or by combining all the data and considering only differences from the annual means. At both Chesterfield and Cape Hope's Advance the hourly means showed a minimum value of the angular direction during the three hours before astronomical midnight. The minimum values for Chesterfield during this period were found to be statistically significant when a comparison was made between them and the angular values for the preceding and following periods. This result is not in agreement with the results quoted by Vegard [13] for Cap. Thordsen and Bossekop. The visual observations at Chesterfield and Coppermine for the morning hours (none made at Cape Hope's Advance) showed a pronounced and significant decrease in the angular direction starting at about three hours past midnight and continuing until daylight.

The experiences of one of us (B. W. C.) at Chesterfield as well as the observational data from the other stations indicate that the greatest changes of angular direction occurred during evening twilight and during the two or three hours preceding sunrise. Obviously grouping the hourly values for a year with the fiducial point at midnight obscures these twilight changes as well as affects the hourly means for the hours of complete darkness. As soon as time permits a reexamination of the diurnal variations will be made using both sunset and sunrise as reference points on the time scale.

Procedure for examining diurnal frequency-characteristics—Numerous methods of investigating the diurnal frequency of auroras are outlined in auroral reports. Usually these include studies of the nightly variation of auroras seen at either hourly or half-hourly intervals, of the nightly variation of faint, moderate, bright, and brilliant displays, and of the nightly variation of the different forms such as arcs, rays, draperies, etc. While these methods of describing the changes during the night are undoubtedly of great value for stations distant from the zone of annual maximum auroral occurrence, they are difficult to apply successfully to stations within or close to this zone. At Chesterfield, for example, hours without auroral activity during darkness were rare, various forms with several of the aforementioned degrees of brightness were often observed simultaneously, and often within a few minutes a quiet arc would change successively into bands with rays, draperies, a corona, and then return to some inactive form making it impossible for a single observer to record more than the gross details.

Other difficulties arise in estimating the probable effect of various auroral situations on geomagnetic disturbance. Is a brilliant localized display more effective than a faint diffuse glow covering the whole sky? Is a rapid latitudinal displacement of a display as important as pulsations or waves of intensity traveling along a relatively stationary display? Should a rapid auroral development be rated higher than an

equally rapid disappearance? And many more questions of a similar type.

For the purpose of this report an auroral character-number was deduced for each hour, the number taking into account the duration, the intensity, the movement, and the areal extent of the display. On the basis of information given in the auroral logs a value of 0, or 1, or 2 was assigned to each of the aforementioned characteristics. The sum of these numbers was taken as the character-number for the hour. Zero was assigned to an hour without aurora, to an hour with only faint aurora, to an hour with no movement within the display and little or no displacement of the display as a whole, and to an hour with no part of the display extending more than about 15° above the horizon; one was assigned to an hour with aurora for half the hour or less, to an hour with moderate to bright forms, to an hour with movement within the display but little or no displacement of the display as a whole, and to an hour with the display having an altitude greater than 15° and covering approximately not more than one-third of the sky; and two was assigned to an hour with aurora for more than half the hour, to an hour with bright and brilliant forms, to an hour with both movement within the display and displacement of the display, and to an hour with the display covering more than one-third of the sky. Only days with little or no cloud throughout the period of darkness were considered. Days with less than six hours of darkness were excluded, and thus for high-latitude stations confining the investigation to the months from October to March, inclusive.

Results—The nightly variation of the mean hourly auroral character-numbers for Chesterfield (47 days), Coppermine (48 days), and Cape Hope's Advance (41 days) is shown in Figure 3. Observations at Cape Hope's Advance were seldom continued past 05^h GMT, so that the variation for the morning hours could not be investigated. Since the values in the early evening and late morning are based on a smaller number of hourly values than the intermediate period they are not as reliable and are joined by dotted lines. The Greenwich times of local or astronomical midnight and geomagnetic midnight for the December solstice are indicated on each curve.

Both Chesterfield and Coppermine show a pronounced maximum for

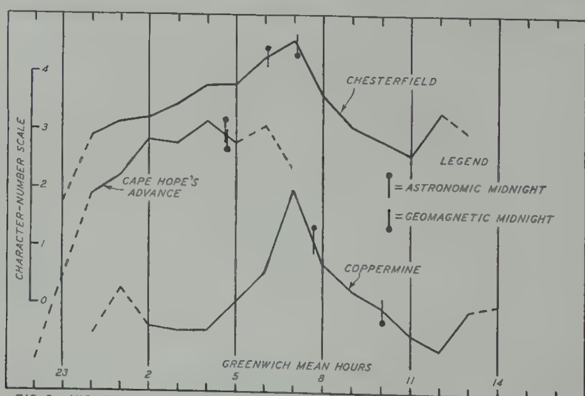


FIG. 3—NIGHTLY VARIATION OF AURORAL CHARACTER-NUMBER AT CHESTERFIELD, CAPE HOPE'S ADVANCE, AND COPPERMINE

the hourly interval centered on 07^{h} GMT. At the former place this maximum is about an hour after astronomic midnight and effectively at geomagnetic midnight, while at the latter it is about two-thirds of an hour before astronomic midnight, and three hours before geomagnetic midnight. The curve for Cape Hope's Advance suggests that the maximum occurs at 04^{h} GMT or shortly before astronomic and geomagnetic midnight.

The report of the British Expedition to Fort Rae during the Second International Polar Year [16] states that the maximum auroral frequency occurred at about $07^{h}45^{m}$ GMT or just after astronomic midnight. Incidentally this is practically the same time for the maximum as computed by Vegard [2] from the observations of 1882-83 at Fort Rae. The report states also that the maximum was one-half to one hour later for the autumn and spring months, and one hour earlier for the winter months.

While our times for maxima are specifically for auroral character-numbers, an examination of the data showed that they applied equally well to maxima of auroral frequency. In addition they can be considered as applying mostly to the winter. Hence, it appears that the nightly maximum of frequency and probably of character-number occurs practically simultaneously over a large region extending northward from the belt of annual maximum frequency to geomagnetic latitude 74° north and lying between geomagnetic longitudes 35° west and 76° west, and that the time of this maximum does not vary appreciably from year to year.[2]

If the indicated maximum at 04^{h} GMT for Cape Hope's Advance is the principal maximum at this place for the night, a very rapid change in the Greenwich time of the maximum must occur to the eastward of Chesterfield. The investigations by Vegard [2] of the nightly frequency at Kingua Fjord (about 400 miles north of Cape Hope's Advance) during 1882-83 showed an early evening maximum, and are a further indication of the rapid change.

Both the curves for Chesterfield and Coppermine show a secondary maximum before sunrise on the longer nights of the year. An examination of the data for individual nights indicates that this increase in the character-number is strongly correlated with considerable auroral activity earlier in the night. Only two cases with activity at the approach of sunrise were reported when auroral activity had not persisted for several hours earlier in the night. In addition the displays during this period of the night differed in appearance from the earlier ones. Faint, diffuse forms, often covering most of the sky, predominated, and their intensity varied rapidly, barely discernible pulses traveling upward to the zenith. In contrast the displays during and shortly after evening twilight have well-delineated forms which vary little in intensity.

In conclusion it appears that the data from these stations offer little or no support to either Vegard's [2] or Hulburt's [3] views on the occurrence of the principal maximum. At both Chesterfield and Coppermine geomagnetic midnight is after instead of before the maximum. If local conditions in the upper atmosphere are a predominating factor these

[2] Casual observations by the writers in the region surrounding Saskatoon during the past six years indicate that the maximum auroral activity occurs at about 07^{h} GMT in the district to the south of this region.

conditions must be fairly constant throughout extensive horizontal sections of the atmosphere.

Acknowledgments—The authors are indebted to J. Patterson, Controller, Meteorological Services of Canada, for the loan of the auroral data, and to the National Research Council of Canada for a grant to finance the investigation.

References

[1] L. Vegard, Phil. Mag., **42**, 47-87 (1921).
[2] L. Vegard, Physics of the Earth, **8**, 579-580 (1939).
[3] E. O. Hulburt, Terr. Mag., **36**, 23-28 (1931).
[4] Kr. Birkeland, Norwegian Aurora Polaris Expedition, 1902-3, **1**, 306-311 (1908).
[5] S. Chapman, Proc. R. Soc., A, **115**, 242-267 (1927).
[6] A. G. McNish, Terr. Mag., **43**, 67-76 (1938).
[7] E. H. Vestine, Terr. Mag., **43**, 261-282 (1938).
[8] E. H. Vestine and S. Chapman, Terr. Mag., **43**, 351-382 (1938).
[9] J. M. Stagg and J. Paton, Nature, **143**, 941 (1939).
[10] T. Alty and F. J. Wilson, Canadian Polar Year Expeditions 1932-33, **2**, 131-149 (1939).
[11] H. U. Sverdrup, Terr. Mag., **33**, 198-203 (1928).
[12] C. Störmer, Kristiania, Skr. Vid. selsk., I, No. 17 (1911).
[13] L. Vegard and O. Krogness, Geofys. Pub., **1**, No. 1 (1920).
[14] B. W. Currie, Terr. Mag., **39**, 293-297 (1934).
[15] J. C. McLennan, H. S. Wynne-Edwards, and H. J. C. Ireton, Can. J. Res., **5**, 285-296 (1931).
[16] British Polar Year Expedition, Fort Rae, N. W. Canada 1932-33, **2** (1937).

Department of Physics, University of Saskatchewan,
Saskatoon, Canada

POLARIZATION-STUDIES OF ECHOES REFLECTED FROM THE ABNORMAL *E*-LAYER FORMED DURING GEOMAGNETIC STORMS

By Leiv Harang

The effect of geomagnetic storms and auroras on the ionosphere at high latitudes in the vicinity of the auroral zone may be summarized as follows: (*a*) Slight magnetic disturbances and faint auroras are accompanied by an increase of the ionization in the region of the *E*-layer. Owing to this abnormal ionization the echoes reflected from the *E*-region may be followed even up to 9 or 12 Mc/sec. This increased ionization sometimes screens off the *F*-echoes completely, in other cases the strongly ionized layer formed in the *E*-region is so thin that a considerable part of the energy penetrates the layer and reflections from the *F*-region are obtained simultaneously. (*b*) Strong magnetic storms and great auroras are accompanied by complete cessation of the echoes on all frequencies over certain time-intervals. This absorption-effect is usually ascribed to the formation of an increased ionization at the lower boundary of the *E*-layer, which causes increased absorption of the radio waves.

Besides these two main aspects of the geomagnetic and auroral influence on the ionosphere in high latitutes, a number of other effects appear, which are now well known and may be summarized as follows: The general absorption increases during the disturbances, the critical frequencies of the F_2- and F_1-layers usually show lower values, and the structure of the *F*-region changes. The latter is manifested on the echo-records in increasing reflection-heights and often a more marked F_1-ledge.

The abnormal *E*-ionization appearing during slight geomagnetic disturbances and auroras has been studied in a number of cases, and it has been shown that the maximum values of the frequencies on which echoes are obtained often closely follow the degree of the geomagnetic disturbance during an evening or night. If we therefore interpret the maximum value of the frequency on which echoes are obtained from the abnormal *E*-layer as a *critical* frequency, this gives a measure for the maximum electron-density in the *E*-region formed during the disturbance [see 1 of "References" at end of paper].

This interpretation of the maximum value of the frequency on which echoes are obtained from the abnormal *E*-layer as a *critical* frequency may be open to certain doubts, especially because the echoes usually do not penetrate the layer as two separate components, but appear at uniform heights over the whole frequency-range until the echoes at a certain frequency disappear.

To solve this question polarization-tests were undertaken. In Tromsö the inclination of the Earth's magnetic field is 77°. For vertical propagation we therefore here very nearly have to deal with the longitudinal type of propagation. According to the magneto-ionic theory of propagation [2], the echoes when reflected will be split up into two components each circularly polarized with opposite senses of rotation. In terms now commonly used this means that the signals when penetrating the layer

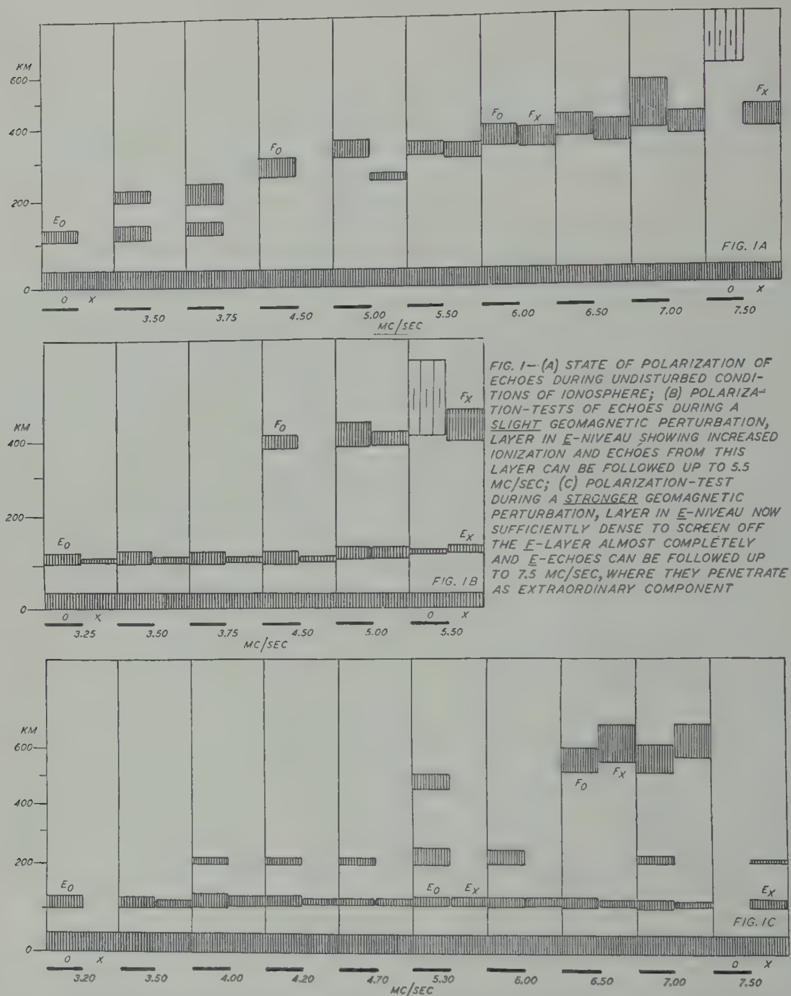


FIG. 1—(A) STATE OF POLARIZATION OF ECHOES DURING UNDISTURBED CONDITIONS OF IONOSPHERE; (B) POLARIZATION-TESTS OF ECHOES DURING A SLIGHT GEOMAGNETIC PERTURBATION, LAYER IN E-NIVEAU SHOWING INCREASED IONIZATION AND ECHOES FROM THIS LAYER CAN BE FOLLOWED UP TO 5.5 MC/SEC; (C) POLARIZATION-TEST DURING A STRONGER GEOMAGNETIC PERTURBATION, LAYER IN E-NIVEAU NOW SUFFICIENTLY DENSE TO SCREEN OFF THE F-LAYER ALMOST COMPLETELY AND E-ECHOES CAN BE FOLLOWED UP TO 7.5 MC/SEC, WHERE THEY PENETRATE AS EXTRAORDINARY COMPONENT

on the highest frequency will penetrate as an extraordinary component with a right-hand sense of rotation.

The experimental arrangement here used was similar to that first used by Ratcliffe and E. L. C. White [3]. Two vertical frames standing at right-angles to each other were coupled together in such a way that the arrangement of antenna was *either* sensitive only for the left-handed (ordinary) *or* right-handed (extraordinary) component. The two conditions for reception could be changed over rapidly by means of a relay. Tests could be taken on 11 fixed frequencies in the range 3 to 11 Mc/sec in the course of 20 to 30 minutes.

In the following, polarization-tests of the echoes during disturbed conditions of the ionosphere with abnormal E-layers will be treated. The tests obtained with the antenna-arrangement mentioned are shown schematically in Figures 1-A, 1-B, and 1-C and the records are repro-

duced in Figures 2-*A*, 2-*B*, and 2-*C*. (In Fig. 1 the words "niveau" in title should read "region.")

During normal conditions of the ionosphere (see Fig. 1-*A*), we obtain on lower frequencies only the *E*-echoes. The polarization-tests show that these echoes only consist of the ordinary component, whereas the extraordinary component is completely absorbed. This is in accordance with the earlier observations by Ratcliffe and White [3].

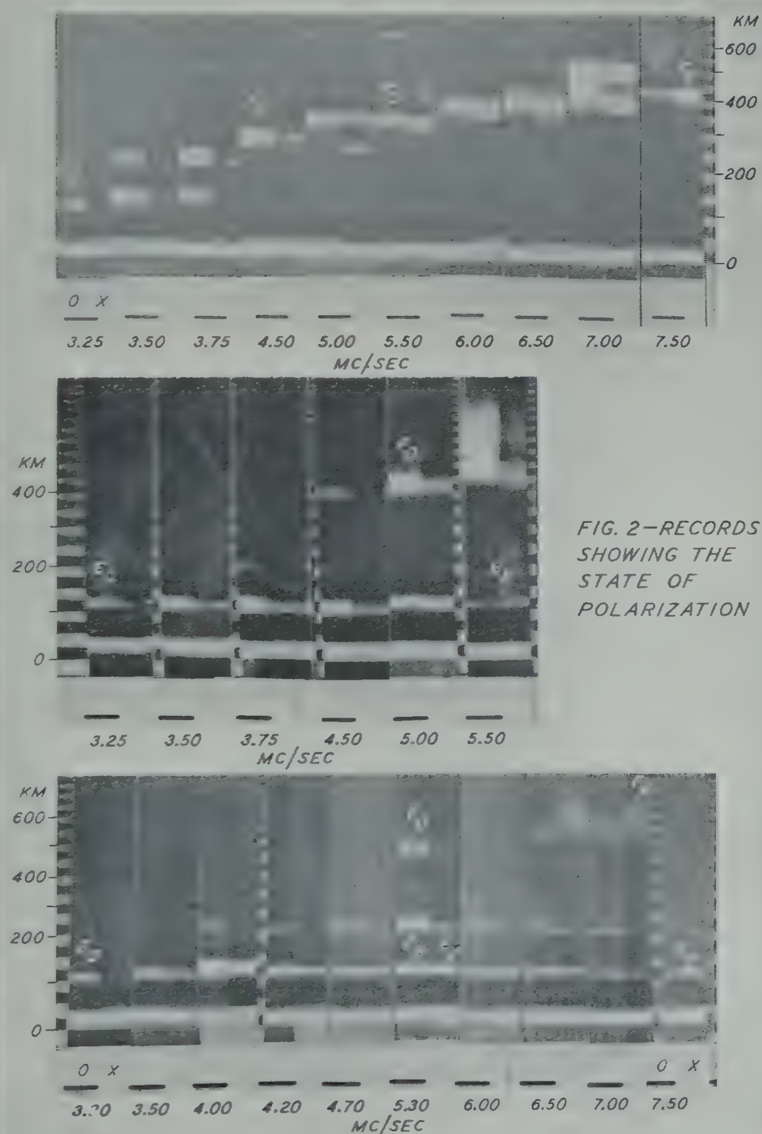


FIG. 2—RECORDS SHOWING THE STATE OF POLARIZATION

When a slight geomagnetic disturbance appears which is followed by an increase in the ionization in the *E*-region, we have in a number of cases noticed that *both* components of the *E*-echoes may appear on lower frequencies of 3 to 3.5 Mc/sec, although the ordinary component always is considerably stronger than the extraordinary. On higher frequencies both components appear with equal intensities, and when penetrating the *E*-layer the extraordinary component appears as the stronger or even as the only one. This gradual change in the records is given in Figures 1-*B* and 1-*C*, and has been confirmed by a number of tests over several months.

The polarization-studies of the echoes reflected from the ionized layer in the *E*-region formed during geomagnetic perturbations have given the results which can be summarized as follows: (1) On lower frequencies the echoes mainly consist of the ordinary component, but in a number of cases a faint or medium extraordinary component has also been noted; this faint extraordinary component is usually not found in the echoes reflected from the normal *E*-layer. (2) On higher frequencies just before the waves penetrate the layer only the extraordinary component is received.

The tendency to reflect the extraordinary component on lower frequencies with noticeable intensity is explained by the sharp lower boundary which the layer formed must exhibit. On account of the steep gradient the waves will penetrate only a short distance into the layer before conditions for reflection occur, and the differential absorption of the components will be less. The fact that the virtual heights of the reflections over the whole frequency-range are approximately constant, supports this point of view deduced from the polarization-effects that the lower boundary of the layer is very sharp.

The occurrence of only the extraordinary component on the highest frequency on which the echoes appear, shows that highest frequency on which the echoes are obtained must be regarded as a *critical* frequency of the layer in the usual sense, and it is thus possible to calculate the maximum electron-density of the layer formed during geomagnetic perturbations using the appropriate formulas. In the cases here dealt with it would have been correct to use the formula for the electron-density containing the extraordinary ray.

For his valuable assistance during the construction of the apparatus and during the observations I wish to express my most sincere thanks to W. Stoffregen. My thanks are also due to Norsk Rikskringkasting, which has given financial grants for carrying through the program of observations.

References

[1] L. Harang, Beitr. Geophys., **46**, 438 (1936); Terr. Mag., **41**, 143 (1936) and **42**, 55 (1937).

[2] E. V. Appleton, J. Inst. Elec. Eng., **71**, 642 (1932).

[3] J. A. Ratcliffe and E. L. C. White, Phil. Mag., **16**, 125 (1933).

Auroral Observatory,
Tromsö, Norway

THE VARIABILITY OF LUNAR MAGNETIC VARIATION[1]

By O. Schneider

Abstract—A possible way of localizing the lunar diurnal variation L in the ionosphere is by studying its variability and its relations to the solar variation S. This problem is complicated by the impossibility of separating two oscillations of so nearly equal wave-length. It is suggested to investigate, instead of deviations on individual days, rather the mean variability of L by trying to deduce from frequency-distributions for (S+L) those for L alone. The question is analyzed in harmonic dials which contain Fourier coefficients grouped into elliptical point-clouds. The ellipses representing such frequency-distributions would follow a periodicity with a wave-length of about a week if the statistical fluctuations of S and of L were completely independent of one another; if there existed on the other hand a strict correlation by which phase-shifts and relative-amplitude deviations of the solar and lunar waves were connected, the period of that oscillation in the parameters of the elliptical distributions should be semimonthly. A mathematical model is suggested for an intermediate stage which allows for any proportion between two such parts of the L-variability, one correlated and the other independent. This permits us to define some kind of correlation-index between L and S. Examples are given illustrating the behavior of such a model-distribution for different degrees of correlation. By means of empirical data from Batavia it is shown that very large series of observations would be necessary for proving the validity of the model; the present preliminary results seem to confirm, however, former presumptions of the author that the variability of L contains a considerable independent part, not correlated with S.

§1—*Introduction*

When Chapman, Stagg, and Bartels had demonstrated and analyzed the strong variability of the solar geomagnetic variation S it had been expected at once that L, the lunar variation, would behave in a similar way, namely, that it would be widely different even on days with apparently most uniform conditions. The question is identical, to a certain extent, with the problem of separating L from S. To do this, it will be necessary in most cases to consider individual days, whether by subtracting S in some way and interpreting the rest as L, or by concluding from the mere shape of (S+L), the total diurnal variation, upon a special shape of L. Both procedures are affected by a fundamental insecurity because it never is possible to say with absolute determination whether the eliminated part contains exclusively S (or L); the reason for this is the nearly equal length of the periods of L and S, which has the consequence that at certain epochs of the lunation a phase-displacement of S, for instance, has practically the same influence on (S+L) as would produce an amplitude-deviation of L, etc.

When in 1935 an attempt was made to analyze the diurnal variability of L and to put it in relation to that of S as illustrated so evidentially by Bartels' point-clusters in harmonic dials, only qualitative results could be obtained although it seemed obvious that the material was ample enough [1].[2] In that essay the method of statistical investigation of two-dimensional distributions for the harmonic coefficients of (S+L) was used. It seemed to the author that interdependence between L and S must result in a typical semimonthly variation of the parameters for such distributions of (S+L), while independence would have been manifested in a nearly weekly periodicity of those parameters. Certain indications for the existence of a periodicity of the latter kind were interpreted as demonstrating that "L reveals a marked independent scattering," a result that has been confirmed recently by Bartels and

[1]Published by permission of the Director de Meteorología, Geofísica e Hidrología, Ing. Alfredo G. Galmarini, Buenos Aires.

[2]For references see list at end of paper.

Johnston [2] who proceeded quite distinctly. Their paper also gives a clear impression of the difficulties standing against a separation of S and L on single days, obstacles, which even are, in the present author's opinion, of fundamental character, mitigated only by the quasi-persistence-tendency present in both phenomena. In order to make any statements more detailed than those concerning mean values it will therefore be necessary to draw the widest possible conclusions from the statistical distributions of (S+L). An attempt will be made to utilize, instead of the new procedure of semimonthly analysis of daily ranges as developed by Bartels and Johnston in [2], the older method based on harmonic coefficients for 24-hourly intervals plotted in harmonic dials by groups according to lunar age.[3]

§2.—*The variability of (S+L) in harmonic dials for solar days*

It is already known that the superposition of two shifts (namely, the lunar day as compared with the solar one and the L-waves in the lunar day itself) makes the lunar components of the daily variation also shift during the solar day, the phase-shift for L_1 and L_2 being equal to 2π during half a month.[4] In a harmonic dial for solar time the vector which represents (S+L) will therefore in the average make a periodical semimonthly movement in which its end-point describes a circle about a center which has to be interpreted as the end-point of the vector for S alone. For characterizing lunar age we use the index μ after Ad. Schmidt [6, 7]. It is connected with the index ν used by Bartels and Johnston in [2] by means of $\mu=(24-\nu)$; both always refer to a whole day. $\mu=0$ corresponds to new Moon. Figure 1 gives an example of two point-clusters representing harmonic coefficients for the semidiurnal wave (S_2+L_2) of the east component at Batavia. The data refer to 715 undisturbed summer days ($C\leqq 1.1$) of the years 1906 to 1929 without regard to sunspot-numbers. Restriction to $R=0$ would have given somewhat smaller but very similar clouds. These coefficients are taken from computations made in 1935 with the aid of the Department of Terrestrial Magnetism of the Carnegie Institution; they were used for the paper [1], but were not given in detail there. They have now been slightly adjusted by applying corrections for seasonal change to each individual day. Two kinds of symbols have been used in the graph, one for days with $\mu=0$, 1, 12, and 13, and the other for $\mu=6$, 7, 18, and 19; that is, in the first group those about new Moon or full Moon, and in the second those about the first or last quarter. The clouds show the known strong scattering both in phase and amplitude; the former oscillates by about 180° in extreme cases and about 90° in a great number of normal cases (6 or 3 hours' difference, respectively, between the culmination-times of the waves). The amplitude easily may be ten times greater on certain days than on others. The centers N and M of the two groups appear clearly separated, as theory requires, in positions opposed to one another as referred to the general center of gravity C[5]. Nevertheless, individual days of each group may deviate so far from their normal behavior that in a vast region in the middle of the cluster we find symbols of both kinds mixed. It even may happen that a day has an L-part which apparently is quite contrary to the mean behavior of its μ-group; one of these cases

[3]As for harmonic dials and statistical methods see [3] and [4].

[4]A somewhat more detailed description of these facts is given, for instance, in [5].

[5]For the determination of C the days belonging to all other groups of Moon-phases were also used.

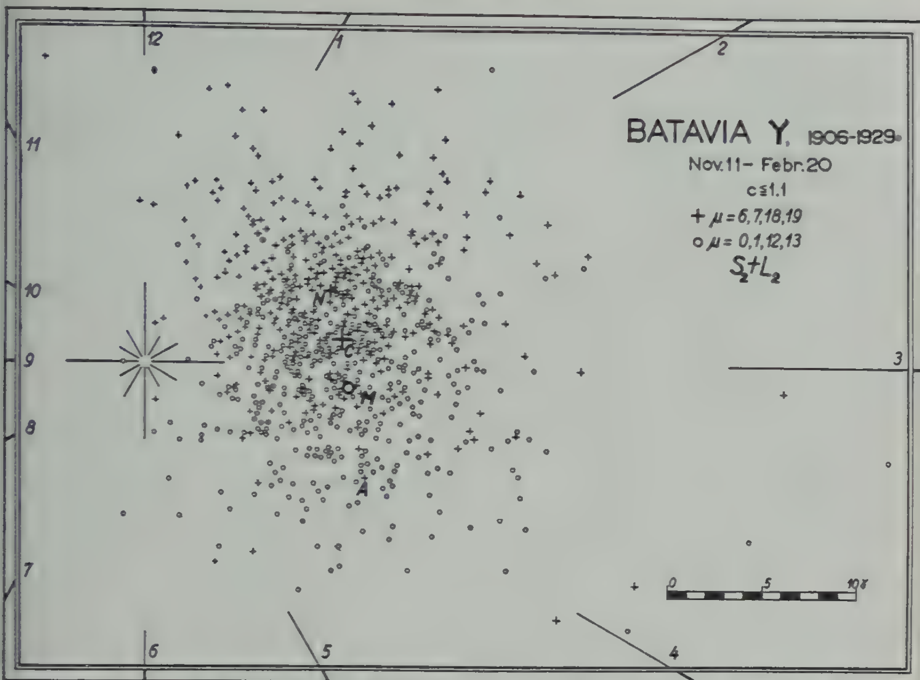


FIG. —HARMONIC DIAL FOR SEMIDIURNAL WAVES (S_2+L_2), BATAVIA, EAST COMPONENT, SOUTHERN SUMMER, 1906-29, UNDISTURBED DAYS ($C\leqq 1.1$), WITHOUT DISTINCTION OF SUNSPOT-NUMBERS; DIFFERENT SYMBOLS FOR TWO MOON-PHASE GROUPS (NOTE MARKED TENDENCY OF EACH GROUP TO PREVAIL IN OUTER REGIONS)

(November 22, 1915) has been marked by the letter A. If we wanted to use this single day, which according to its Moon-phase belongs to the "upper" group of the Figure, and tried to compute from it the lunar semidiurnal wave L_2, we should have to suppose for instance that S_2 had been normal or represented, say, by the vector with end-point C; thus a wave L_2 would result which not only had an amplitude three times greater than the normal one (CN) but also a phase shifted by about 180°. But nothing prevents us from supposing on the contrary that of the two vectorial components the sum of which has this end-point A, the lunar one was normal and the solar part, while nearly normal in amplitude, was considerably shifted downwards in phase.

This example is typical of the difficulty of determining the deviation of an individual L from the normal one. The mathematical expression of this dilemma, which is due to the nearly identical length of periods of L and S, is the simple fact that any given sum of two vectors may be imagined as the result of an infinite number of possible pairs of components. The similarity of wave-lengths would be no obstacle if L and S were composed, in spite of their variability, of a finite number of waves of strictly sinusoidal or any other determined shape. We could then make an analysis by lunar time and another by solar time; in each set of Fourier coefficients S as well as L would be contained partially, but of slightly different composition in both cases, whereby a complete separation of the individual L and S would become possible. In reality, however, both phenomena are affected by numerous small fluctuations which produce contributions to the harmonic coefficients greater by far than those differences between the results which would be obtained from the two

forms of analysis mentioned, namely, by solar time or by lunar time[6]. After all, we must accept the fact that two geophysical processes of fairly distinct origin, though similar and connected with each other, defy detailed analysis.

Among the possible procedures for obtaining at least approximate information on L alone, that used by Bartels and Johnston is to be mentioned in the first place [2]. Their method has the great advantage of analyzing the whole of S or L without disintegrating them into partial waves. On the other hand, as they themselves admit, it lacks the possibility of distinguishing, at certain Moon-phases, amplitude-deviations of L from phase-shifts of S. In contrast with this, the following attempt will try to do without such restriction; it must, however, operate again with the separation into partial waves. But we may note here that already the diurnal and semidiurnal components suffice largely to determine the main features of a normal magnetogram.

The concrete problem is the following: (1) Is it possible to determine at least a distribution of L_1 and L_2, for example, in the form of an elliptical distribution in the harmonic dial? This would permit us to say whether L, absolutely or relatively, is more variable than S, and whether such a variability affects to a higher degree the phase or the amplitude. Besides, it would be easier, then, to find the distributions for S_1 and S_2 alone; it must be kept in mind that all scattering diagrams published so far as referring to S are representing in reality (S+L). (2) Does there exist any kind of correlation between the variability of S and that of L, and by what kind of numerical index might it be measured?

A solution of these problems would help us to determine whether S and L are as similar as for ionospheric process which produces them. The steps taken for answering these questions were the following: At first a qualitative study was made as to what sort of distribution for (S+L) must result in a harmonic dial if we superpose upon a determined elliptical distribution of S (which apart from sampling errors is assumed to be independent in size and orientation from lunar age), one for L not correlated with the former one, and also constant in size; it was supposed, moreover, that this L-distribution maintains a constant angular orientation with respect to the vectorial component L contained in the average (S+L), similarly as did the solar distribution with respect to the mean S. As the lunar vectors for L_1 and L_2 make one anti-clockwise revolution of 2π in half a month (for μ diminishing from 12 to 0) the corresponding partial ellipse, too, would describe a whole revolution of 360° with respect to the fixed coordinate-system represented by the solar-time harmonic dial. That is to say that during this half-lunation it passes twice through all possible angular positions relative to this coordinate-system and to the first (solar) ellipse. The result of such a superposition between the fixed S-ellipse and this L-ellipse depending on μ would be, it was supposed, an (S+L)-ellipse equally oscillating twice in orientation and ellipticity.

On the other hand we might ask what aspect would offer the (S+L)-distribution if each individual lunar vector would be connected to the corresponding solar one by a geometrical transformation in the following way: The relative amplitude-deviation of the lunar vector is the same as that of the solar one, and the phase-shift is identical for the two waves. It was found that the resulting distribution, elliptical also, would oscillate

[6]In [1] an example is given showing the smallness of this difference which is quite insignificant as compared with the scattering.

in its parameters only once during half a lunation. The fact stated in [1] that there predominates at Batavia, for southern summer and east component, the weekly character of the periodicity was therefore interpreted in the sense that there exists no such correlation between L and S.

Now it is evident that here as in most geophysical phenomena the alternative probably will not be to represent the process in the extreme form of either a strictly fulfilled mathematical law or complete statistical independence; in reality there will exist an intermediate degree of dependence. Therefore a model distribution of (S+L) was projected in which both described tendencies were present. The considerations which led to this model apply to (S_1+L_1) as well as to (S_2+L_2).

§3—*Statistical principles and symbols*

Before giving the mathematical description and interpretation of such distributions we shall define the quantities and symbols to be used. As for the very elementary facts on two-dimensional distributions, not derived here, reference is made to the extensive existing literature on the subject, [3] and [4] for instance.

(3.1) x, y are coordinates of a point in a system the x-axis of which is directed upwards; in some cases we shall use these letters instead of the harmonic coefficients a and b. The coordinate-system is an harmonic dial.

(3.2) $r(u, v)$ is the ordinary correlation-coefficient between two variables u and v. Instead of r occasionally R will be used as a symbol for the correlation-coefficient in order to distinguish between different distributions.

(3.3) σ_x, σ_y are the standard deviations of the variables x and y, measured along the coordinate-axes. Scatterings along the axes of the probable ellipse will be characterized by Greek letters as subscripts; thus σ_ξ is the standard deviation along the major axis, σ_η that along the minor axis. Between the two pairs of parameters there is the relation

(3.4) $$\sigma_\xi^2\sigma_\eta^2=\sigma_x^2\sigma_y^2(1-[r(x, y)]^2)$$

(3.5) $$\sigma_x^2+\sigma_y^2=M^2=\sigma_\xi^2+\sigma_\eta^2$$

For σ we shall write ρ in some cases as a symbol for standard deviation.

(3.6) P_1, P_2 are the lengths of the major and minor axes of the probable ellipse.

(3.7) Π is a measure for the size of a probable ellipse; it is equal to $(P_1^2+P_2^2)=M\sqrt{\log_e 4}$, with M according to (3.5).

(3.8) ϵ is the ratio between the ellipse-axes, that is, (P_1/P_2).

A frequently occurring function of ϵ is

(3.9) $$Q=(\epsilon^2-1)/(\epsilon^2+1)$$

(3.10) θ is the directional angle of the ellipse, being measured between the positive x-axis and the major axis of the ellipse, positive to the right. It is defined by

$$\tan 2\theta=2r(x, y)\sigma_x\sigma_y/(\sigma_x^2-\sigma_y^2)$$

(3.11) ψ is the angle of phase of a wave represented in a harmonic dial.

(3.12) λ is an angle in the harmonic dial serving to characterize the phase of lunar waves or parts thereof. It has the value zero for lunar vectors pointing in the direction of the x-axis, and increases positively in anti-clockwise sense. For the diurnal and semidiurnal wave, λ changes by 4π during a month, so that days separated by six units (hours) in μ, have in the average a λ different by 180°.

Combination of (3.4), (3.5), and (3.10) yields some more relations of the values contained in them, which will be useful for future calculations.

$$2r\sigma_x\sigma_y = (\sigma_\xi^2-\sigma_\eta^2)\sin 2\theta \tag{3.13}$$

$$2\sigma_x^2 = (\sigma_\xi^2-\sigma_\eta^2)\cos 2\theta+\sigma_\xi^2+\sigma_\eta^2 \tag{3.14}$$

$$2\sigma_y^2 = -(\sigma_\xi^2-\sigma_\eta^2)\cos 2\theta+\sigma_\xi^2+\sigma_\eta^2 \tag{3.15}$$

From the last two equations we may obtain, of course, also σ_ξ^2 and σ_η^2.

All symbols above defined may have additional subscripts a, b, c, d, and e by which distinction is made between the different distributions considered; their meaning will be explained in the following section.

§4—*Hypothetical model for the combined* (S+L)*-variability*

We assume that the whole phenomenon (S+L) or its symbolic representation in the harmonic dial is composed on individual days of five portions partly constant and partly individual, as illustrated in Figure 2 (in which for reasons of clearness no care has been taken to preserve the natural proportions between the components; thus, for example, $\overline{L}_0$ is far too great as compared with $\overline{S}_0$):

(I) The mean solar vector $\overline{S}_0$ as characterized by the amplitude S_0 and the phase ψ_0.

(II) The variable part of S which must be added to the mean value and which would make the points for individual days form a frequency-distribution a if S existed alone (without L).

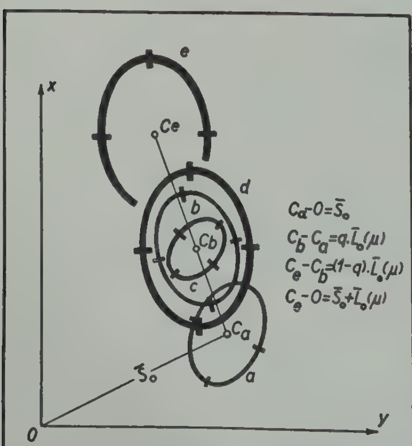


FIG. 2

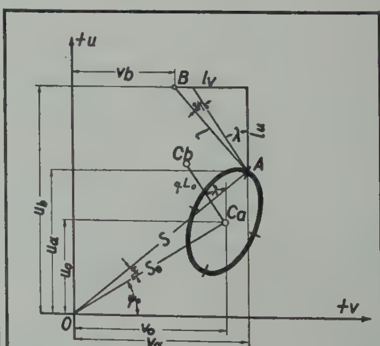


FIG. 3

FIG. 3—MODEL FOR SUPERPOSITION OF VARIABILITY OF S, SUPPOSED ELLIPTICALLY DISTRIBUTED IN A HARMONIC DIAL, AND THE PART OF L CORRELATED WITH S (DIMENSIONS AND MEAN VECTORS CHOSEN ARBITRARILY, FOR CLEARNESS)

FIG. 2—HYPOTHETICAL MODEL OF STRUCTURE OF (S+L)-VARIABILITY AS REPRESENTED IN HARMONIC DIAL: (a) ELLIPTIC DISTRIBUTION COMPRISING SCATTERING OF S ALONE; (b) INCLUDES, MOREOVER, CORRELATED PART OF L; (c) REPRESENTS REMAINING PART OF L-VARIABILITY, NOT CORRELATED WITH S; (d) IS RESULT OF STATISTICAL SUPERPOSITION OF (b) AND (c); (e) IS CONGRUENT TO (d) AND PRODUCED BY PARALLEL SHIFT, ACCORDING TO REMAINING PART OF MEAN L, NOT VARIABLE

(III) A certain portion of L containing part of its variability and, as the mean of it, a constant part $q.\overline{L}_0(\mu)$ of the whole $\overline{L}_0(\mu)$; these two joined, when added to the vectors of the distribution a give the distribution b. The part of the variability of L mentioned here is that which we assume to be strictly correlated with the variability of S in the sense of the following mathematical transformation: On each day the lunar component contributing to b is deviated from the average direction λ by the same angle $\delta\psi_0$ (positive or negative) as is the solar vector of this day from the mean direction ψ_0; besides it is longer or shorter than the mean portion $q.\overline{L}_0(\mu)$ in the same proportion as the corresponding solar vector is longer or shorter than $\overline{S}_0$. This method of transforming individual points of the distribution a into those of b is shown in Figure 3.

(IV) The remaining part of the total variability of L, consisting of additional vectors statistically independent of those described under (III), and forming a distribution c with the mean value 0. Similarly as the merely solar distribution a has a determined orientation θ_a which defines a fixed angle $(90° - \theta_a - \psi_a)$ between the ellipse and the mean S, we now suppose that c also maintains a determined orientation δ_c with respect to $\overline{L}_0(\mu)$, thus depending on λ. This angle δ_c between $\overline{L}_0(\mu)$ and the major axis of the distribution c is $(\lambda + \theta_c)$, so that

$$\theta_c = \delta_c - \lambda \tag{4.1}$$

The new distribution d obtained by adding c to b is greater than both c and b, but has the same center with them.

(V) The remaining part $[(1-q).\overline{L}_0(\mu)]$ of the total $\overline{L}_0(\mu)$; the portion $q.\overline{L}_0(\mu)$ has been described under (III). V is constant and therefore causes for each vector of d only a parallel shift of its end-point, yielding thus the distribution e. As it is congruent with d the investigation of the latter is sufficient for our present purposes. It is e which we obtain from observational data; it comprises all constant and variable components.

This scheme for the structure of (S+L) is of course an idealization as the part of L correlated with S (if it exists at all) must not necessarily depend on S in phase and amplitude according to exactly the law that has been supposed in (III). The assumptions made are, however, for the moment the most plausible ones. They are probably more complete and closer to actual conditions than a scheme which considers exclusively amplitudes. According to the present model, factors that advance the solar partial waves influence the correlated part of the lunar ones in the same sense and to the same degree.

In quite the same way as that just stated for the correlated part of L we also may question with respect to the independent one: Does it behave so similarly to S (as far as its dispersion is concerned) as has been supposed in our model, namely, is it distributed in an ellipse which maintains a definite orientation with respect to the corresponding mean lunar vector [see (4.1)]? But in this case also, we must first base the model on the simplest assumptions.

The lunar variation may be, *a priori*, strictly connected to, as well as completely independent of S, though the most probable case is, after all, that which geophysical experience suggests, an intermediate stage between these two extremes. It must be stated, however, that we do *not* postulate unconditionally that L must contain any correlated portion at all; the goal of the investigation is, on the contrary, to determine whether such a part of the total variability of L is insignificant or appreciable, or, in other words, whether the difference in size between the distributions a and d is due primarily to the influence of b or rather to that of c. Our model admits the extreme cases that either c is zero (being, then, the whole L-variability contained in the "correlated-portion"-distribution b), or that a coincides with b because of complete absence of any correlated part in the L-variability, which then would be represented by c alone.

It is necessary to state that, in the scheme described, some details have been left out of consideration; it was not yet possible to take them into account although some influence on the results may be supposed. It would be an interesting theme for future investigations to try to analyze this influence. The facts referred to are the following.

(a) In order to gather a sufficient number of points into a single distribution, in practical computations, one must form groups of days the lunar ages of which are not exactly coincident. This means that in such a distribution λ also is not quite uniform, and therefore the empirically found parameters [see (8.6) to (8.12) of §8] represent some kind of average values. In the harmonic analysis this might be taken into account by multiplying by the known correction-factors for smoothing effect [8]; the result is, however, only an approximation, since the mentioned superposition causes a systematical deformation of the distributions d and possibly even transforms a sum of "normal" primary distributions into a slightly asymmetrical final one.

(b) The days or time-intervals used for deducing L should in reality be selected not only with respect to lunar age, but also according to lunar distance, declination, etc.—elements which are not regarded in the classification by μ.

(c) The analysis of L in intervals of *solar* days deforms somewhat its true shape (see [1], for instance); this effect may be corrected only in mean values, while for individual days it is impossible to eliminate it, quite the same as occurs with L itself. Moreover, the deformation of the semidiurnal wave is affected also by the diurnal one, a fact which makes an elimination still more difficult because of the probable correlation between L_1 and L_2.

These restrictions should be kept in mind when interpreting the results from the following considerations. We can now raise the question: What are the features of the distribution d for a given λ if, in addition to $\overline{S}_0$, ψ_0, $\overline{L}_0(\mu)$, the distributions a and c are given by their probable ellipses, say, as well as the factor q occurring in b? The solution will be given in the following two sections. d contains, as will be seen, the original values in a relatively simple form, especially q and the parameters of the ellipses a and c. As d is the empirical distribution as found in practical analysis of observed geomagnetic data, it is evident that we possess a means of clearing by inversion of the procedure to be described here, for the then unknown parameters.

§5—*Synthesis of the distribution for* $S+qL$, *comprising the solar wave and the correlated part of the lunar one*

Let the distribution a be given by its characteristic values S_0, ψ_0, P_{a1}, P_{a2}, and θ_a (see Fig. 3). The problem is to build up upon it the new distribution b, as defined by §4 (III), if q, $\overline{L}_0$, and λ (3.12) are also given. It will be shown that b is elliptical if a is; that its center is defined by the vector $\overline{S}_0+q.\overline{L}_0(\mu)$, and that its parameters are

$$P_b^2=P_a^2[1+k^2-2k\sin(\lambda-\psi_0)] \tag{5.1}$$

(holding with sub-indices 1 or 2, that is, for major or minor axis)

$$\tan\theta_b=\frac{\sin\theta_a+k\sin(\triangle-\lambda)}{\cos\theta_a+k\cos(\triangle-\lambda)} \tag{5.2}$$

where

$$k=q(L_0/S_0) \tag{5.3}$$

and

$$\triangle=\theta_a+\psi_0-90° \tag{5.4}$$

For proof it is sufficient to demonstrate the transformation of one single ellipse characteristic for a, for example, the probable one, because any other, for instance one with $f.P_{a1}$ and $f.P_{a2}$ as axes, gives a geometrically similar result. Let the point A situated on the circumference of the probable ellipse be defined by the coordinates

$$u_a=u_0+\alpha_{1a}\cos t+\beta_{1a}\sin t \tag{5.5}$$

$$v_a=v_0+\alpha_{2a}\cos t+\beta_{2a}\sin t \tag{5.6}$$

The amplitude of the solar wave, as represented by the vector OA, is

$$S=\sqrt{u_a^2+v_a^2} \tag{5.7}$$

and the phase

$$\psi_a=\psi_0+\delta\psi_0 \tag{5.8}$$

The amplitude of the lunar partial wave, as symbolized by the vector AB is

$$l=q(L_0S/S_0) \tag{5.9}$$

the proportionality thus being determined between the individual solar wave of the day considered and a part l of the lunar wave according to §4 (III). In the same way we fix the phase of this lunar part l by the condition

$$\delta\lambda=\delta\psi_0 \tag{5.10}$$

so that the total angle between AB and the u-axis becomes $\lambda+\delta\psi_0$. Thus the orthogonal components of l are:

$$l_u=q.L_0(S/S_0)\cos(\lambda+\delta\psi_0) \tag{5.11}$$

$$l_v=q.L_0(S/S_0)\sin(\lambda+\delta\psi_0) \tag{5.12}$$

These serve for deducing the coordinates of the point B, which are

$$u_b=u_a+l_u \tag{5.13}$$

$$v_b=v_a-l_v \tag{5.14}$$

By means of (5.3) to (5.12) and expressing the trigonometrical functions

of ψ_0, ψ_a by u_0, v_0, u_a, and v_a, we obtain after some modifications, from (5.13) and (5.14)

$$u_b = u_0 + kS_0 \cos\lambda + [\alpha_{1a} + (k/S_0)(A_1 \cos\lambda + A_2 \sin\lambda)] \cos t + [\beta_{1a} + (k/S_0)(B_1 \cos\lambda + B_2 \sin\lambda)] \sin t \tag{5.15}$$

$$v_b = v_0 - kS_0 \sin\lambda + [\alpha_{2a} + (k/S_0)(A_2 \cos\lambda - A_1 \sin\lambda)] \cos t + [\beta_{2a} + (k/S_0)(B_2 \cos\lambda - B_1 \sin\lambda)] \sin t \tag{5.16}$$

where, with $\nu = 1$ or 2

$$A_\nu = \begin{vmatrix} u_0 & (-v_0)^\nu \\ \alpha_{(3-\nu),a} & \alpha_{\nu,a} \end{vmatrix} \tag{5,17}$$

$$B_\nu = \begin{vmatrix} u_0 & (-v_0)^\nu \\ \beta_{(3-\nu),a} & \beta_{\nu,a} \end{vmatrix} \tag{5.18}$$

It is seen that u_b and v_b have again a structure similar to u_a and v_a, being the expressions in brackets as well as the additive terms before them independent of t. Thus, B is also a point of an ellipse, proving the first part of our statement at the beginning of this section. The center of this ellipse has the coordinates $(u_0 + kS_0 \cos\lambda)$, $(v_0 - kS_0 \sin\lambda)$ so that its distance from that of the a-ellipse is kS_0, which is identical with $q.L_0$, according to (5.3). That proves the second of the statements in our theorem. The fact is of no further interest.

We now define new coordinates for B, referred to the center of b.

$$u'_b = u_b - (u_0 + kS_0 \cos\lambda) = \alpha_{1b} \cos t + \beta_{1b} \sin t \tag{5.19}$$

$$v'_b = v_b - (v_0 - kS_0 \sin\lambda) = \alpha_{2b} \cos t + \beta_{2b} \sin t \tag{5.20}$$

where the coefficients α and β correspond to the terms in brackets in (5.15) and (5.16). To obtain from them the direction and size of the axes of the b-ellipse we must establish a relation between θ_a, P_{a1}, and P_{a2} on one hand and the coefficients α and β of (5.5) and (5.6) on the other hand. Thus let

$$\begin{cases} \alpha_{1a} = P_{a1} \cos\theta_a & \beta_{1a} = -P_{a2} \sin\theta_a \\ \alpha_{2a} = P_{a1} \sin\theta_a & \beta_{2a} = P_{a2} \cos\theta_a \end{cases} \tag{5.21}$$

Consequently

$$\alpha_{1a}\beta_{1a} + \alpha_{2a}\beta_{2a} = 0 \tag{5.22}$$

From these relations it follows immediately that the vertex of a and b corresponds to $t = 0$. We can therefore calculate the quotient

$$\tan\theta_b = v'_b(0)/u'_b(0), \tag{5.23}$$

by inserting $t = 0$ in (5.19) and (5.20) and using for α_{1b} and α_{2b} the terms of (5.15) and (5.16). To simplify the result and to reduce it to the values given at the beginning of this section we must insert the terms (5.21) for the a-ellipse in (5.15) to (5.18). Eliminating in this calculation u_0 and v_0, we obtain (5.2) as was to be proved.

For proving (5.1) one may calculate

$$P_{b1}^2 = \alpha_{1b}^2 + \alpha_{2b}^2 \tag{5.24}$$

$$P_{b2}^2 = \beta_{1b}^2 + \beta_{2b}^2 \tag{5.25}$$

as follows from (5.19) and (5.20) by summing the squares of u'_b and v'_b for $t = 0$ and $\pi/2$, respectively.

Immediate consequences of (5.1) are

$$\Pi_b^2=\Pi_a^2[1+k^2-2k\sin(\lambda-\psi_0)] \tag{5.26}$$

$$\epsilon_b=P_{b1}/P_{b2}=\epsilon_a \tag{5.27}$$

[For symbols see (3.7) and (3.8).]

The conclusion which may be drawn from this section is that the portion of L strictly correlated with S produces, if superposed on it, a distribution b characterized by the following features: Its center is located on a circle described with radius $q.L_0$ about the end-point of the solar-wave-vector; its size and orientation are periodical functions of λ and therefore of lunar age. These functions contain as parameters the ratio k between the correlated portion $q.L_0$ of the lunar wave, and the solar wave, and furthermore the angle which the solar ellipse a makes with the mean solar vector.

§6—*Synthesis of the correlated and the independent portions of L-variability*

According to §4 (IV) the problem to be dealt with in the present section is to find a distribution d the elements of which are vectorial sums of elements from the following two original distributions completely independent of each other, and combined by coordinating at random their respective elements:

(1) The distribution b for (S+qL) as described in the foregoing section, with the characteristic parameters P_{b1}, P_{b2}, and θ_b, considered here as being given.

(2) An elliptical distribution c with mean value 0, representing the remaining portion of the L-variability not correlated with S, and defined by its probable ellipse with the axes P_{c1} and P_{c2} and the directional angle $\theta_c=\delta_c-\lambda$ according to (4.1).

It will be shown that the new distribution d is characterized by the following parameters.

$$\Pi_d^2=\Pi_b^2+\Pi_c^2 \tag{6.1}$$

$$\tan 2\theta_d=\frac{A_b\sin 2\theta_b+A_c\sin 2\theta_c}{A_b\cos 2\theta_b+A_c\cos 2\theta_c} \tag{6.2}$$

where

$$A=Q.M^2 \tag{6.3}$$

Q and M being defined by (3.5) and (3.9); equation (6.3) holds for distributions a, b, c, and d. Two more relations defining d are given in (6.4) and (6.5).

$$A_d^2=A_b^2+A_c^2+2A_bA_c\cos 2(\theta_b-\theta_c) \tag{6.4}$$

$$2r_d(x,y)\sigma_{xd}\sigma_{yd}=A_b\sin 2\theta_b+A_c\sin 2\theta_c \tag{6.5}$$

For proof we suppose two normal distributions to be given by their probability-functions as in (6.6) and (6.7).

$$w_1(x,y)=(1/2\pi\sigma_x\sigma_y\sqrt{1-r^2})\exp\{-(1/2)[(x^2/\sigma_x^2)+(y^2/\sigma_y^2) - (2rxy/\sigma_x\sigma_y)]/(1-r^2)\} \tag{6.6}$$

$$w_2(x,y)=(1/2\pi\rho_x\rho_y)\exp\{-(1/2)[(x^2/\rho_x^2)+(y^2/\rho_y^2)]\} \tag{6.7}$$

writing exp z for e^z. The special form of the second distribution, namely, its position parallel to the coordinate-axes, has been chosen for convenience in the deductions; the result may be generalized afterwards by rotating the coordinate-system by an arbitrary angle. Obviously, for the process of statistical random mixture of two groups of vectors the initial position of the coordinate-system with respect to them is irrelevant. For the same reason both distributions have been considered as being given with the mean value zero, since the resulting one must be centered at the same point because of the symmetrical shape of the functions w_1 and w_2.

Imagine a point (u, v) of the new distribution to be the result of the combination between a pair of vectors with the end-point coordinates (x, y) and $[(u-x), (v-y)]$, respectively. The total probability for (u, v) is then obtained by integration extended over all possible combinations, considering x, y as argument variables. We have thus

$$w(u, v) = \iint_{-\infty}^{+\infty} w_1(x, y) w_2[(u-x), (v-y)] \mathrm{d}x\mathrm{d}y = f \cdot \iint_{-\infty}^{+\infty} I \mathrm{d}x\mathrm{d}y \tag{6.8}$$

$$f = 1/(4\pi^2 \sigma_x \sigma_y \rho_x \rho_y \sqrt{1-r^2}) \tag{6.9}$$

After inserting $(u-x)$ and $(v-y)$ in (6.7) instead of x and y the function I in (6.8) can be transformed into a product of two exponential functions by introducing new variables p and q. One of the two factors, I_1, will be seen to be independent of p and q, while the other can be integrated, using the fundamental theorem of probability calculus

$$\iint_{-\infty}^{+\infty} w(p, q) \mathrm{d}p\mathrm{d}q = 1 \tag{6.10}$$

The integration yields, with the standard deviations and correlation-coefficient from (6.6) and (6.7) equation (6.11).

$$\iint_{-\infty}^{+\infty} I_2 \mathrm{d}p\mathrm{d}q = 2\pi \sigma_x \sigma_y \rho_x \rho_y \sqrt{1-r^2} / [\rho_x^2 \rho_y^2 + \sigma_x^2 \rho_y^2 + \rho_x^2 \sigma_y^2 + \sigma_x^2 \sigma_y^2 (1-r^2)] \tag{6.11}$$

By means of (6.9) and (6.11) we may finally write down (6.8) in the following form

$$w(u, v) = (1/2\pi ST\sqrt{1-R^2}) \exp \{[(u^2/S^2) + (v^2/T^2) - (2Ruv/ST)]/2(R^2-1)\} \tag{6.12}$$

The new distribution has the same structure as that defined by (6.6); so it is also elliptical, with the characteristic parameters

$$S^2 = \sigma_x^2 + \rho_x^2 \tag{6.13}$$

$$T^2 = \sigma_y^2 + \rho_y^2 \tag{6.14}$$

$$R = r\sigma_x\sigma_y / \sqrt{(\sigma_x^2 + \rho_x^2)(\sigma_y^2 + \rho_y^2)} \tag{6.15}$$

As, in "normal" distributions, the sum of the squares of standard deviations taken along any pair of orthogonal diameters is independent of the direction of the coordinate-axes [see (3.5)]

$$S^2 + T^2 \equiv \sigma_x^2 + \sigma_y^2 + \rho_x^2 + \rho_y^2 \tag{6.16}$$

may already be considered as a measure for the size of d free from the restriction implied by the special form of (6.7). So (6.1) is proved, since

the values II distinguish themselves from M only by a constant factor, according to (3.7).

From (6.13) to (6.15) one can also obtain the angle θ^* which the major axis of the new distribution makes with the x-axis of the coordinate-system. It is determined by a formula analogous to (3.10) in which the standard deviations and correlation-coefficient S, T, and R must be inserted. The general solution independent of the specially chosen coordinate-system can be found by the following consideration: Let the two elliptical distributions b and c each be given by its respective M^2, θ, $\epsilon=\sigma_\xi'/\sigma_\eta'$, as referred to any arbitrary coordinate-system, say, S'. By means of (3.13) to (3.15) we calculate from them new parameters referred to a coordinate-system chosen so as to have one axis coinciding with the major axis of c. To these the results (6.12) to (6.15) may be applied, giving parameters which must again be transformed to S', yielding finally the formulas (6.2) to (6.5).

In the considerations of this section all values which have subscripts b can be reduced to terms of the distribution a and the factor k by means of the results of §5. So seven values (besides the phases and amplitudes of the mean solar and lunar waves) suffice to compose the definitive ellipse d, namely, three for characterizing each of the primary ellipses a and c, and the factor k necessary to define the transformation of a into b. In the following section are given three concrete examples of such compositions chosen to demonstrate the influence of different proportions between the two hypothetical parts which constitute L.

§7—Behavior of the model distribution for (S+L) as calculated in three typical cases

The examples are based on conditions not very different from those stated in a former paper [1] for Batavia for Y, southern summer, semidiurnal wave (S_2+L_2), on undisturbed days. We assume in the three cases the amplitude S_2 of the solar wave to be 10γ and the phase $\psi_0=0°$ (observed were about 10.3γ and $8°$); the distribution a of S_2 alone was chosen as being characterized by the two-dimensional standard deviation $M_a=5\gamma$, the ellipticity $\epsilon_a=1.414$ and the directional angle $\theta_a=0°$. L_2 was supposed to be of amplitude 2.5γ and phase $90°$, so that for $\mu=0$ the angle λ would be zero also. The portion of L not correlated with S was considered as being distributed in an ellipse c with the ratio of axes $\epsilon_c=1.732$ and the directional angle $\delta_c=0°$, so that $\theta_c=-\lambda$ [see (4.1)]. Finally, for M_c, the size of the ellipse, were taken the amounts $2\gamma, 1.414\gamma$, and 0γ, respectively, and for k [see (5.3)] the values 0, $0.283=(1/5)\sqrt{2}$, and 0.4. In the first case, that of $k=0$, the portion of L correlated rigorously with S is also zero, owing to (5.3), so that the synthesis is limited to mixing two independent point-clusters; in the third case there is no independent part, as M_c is zero. Case 2 is an intermediate example.

The parameters M_c were chosen, different in the three cases, to make the term $(k^2M_a^2+M_c^2)$ constant, which one may interpret as the contribution of L-variability to be added to M_a^2 in order to obtain the total (S+L)-variability as represented by $[M_a^2+(k^2M_a^2+M_c^2)]$. In fact, the latter value is the average standard deviation of the final d-distribution, as can be seen by inserting in (6.1) the right-hand side of (5.26), taking the mean for all values of λ, and remembering (3.7). Now, in the stated expression $(k^2M_a^2+M_c^2)$ the first term varies with k, and thus the second

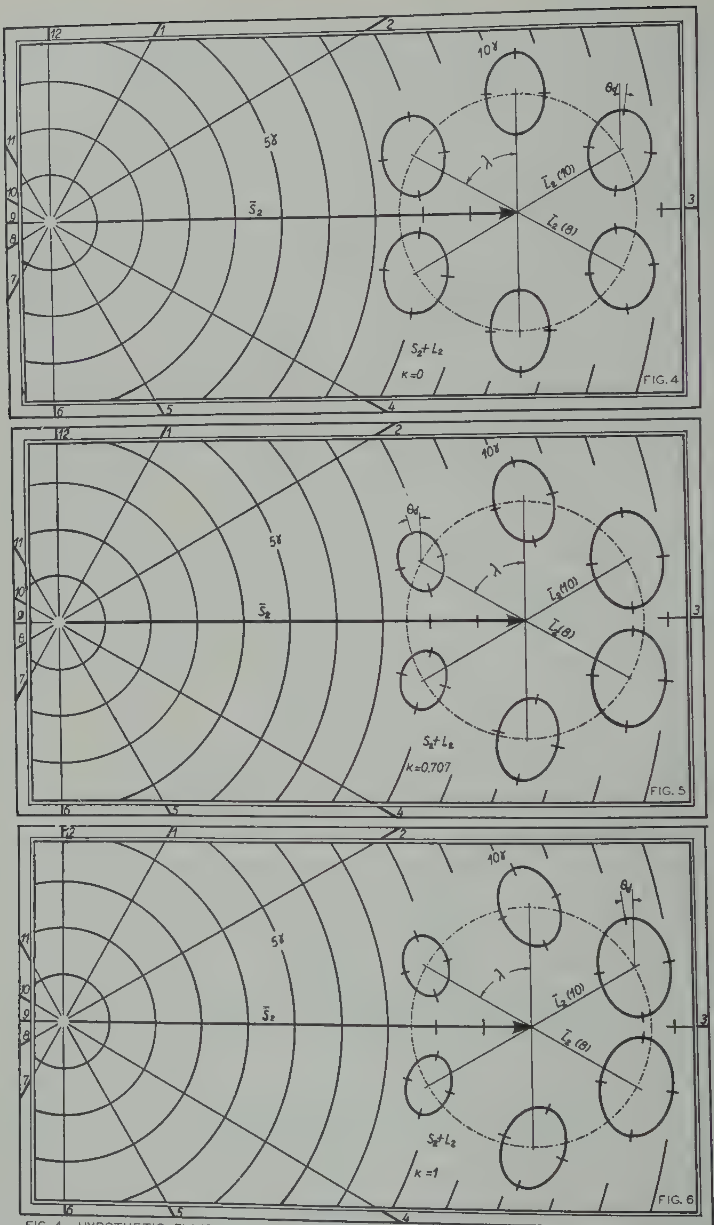


FIG. 4—HYPOTHETIC ELLIPTICAL DISTRIBUTIONS FOR (S_2+L_2), DEPENDING ON LUNAR AGE; AXES REDUCED BY FACTOR 0.171 AS COMPARED TO PROBABLE ELLIPSES, TO AVOID MUTUAL SUPERPOSITION; EXTREME CASE OF MISSING CORRELATION

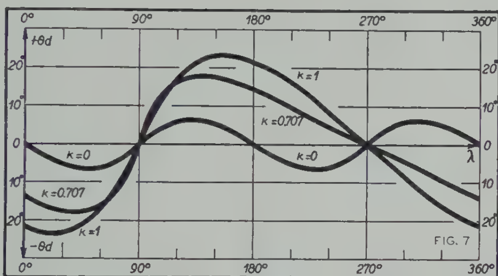
FIG. 5—DISTRIBUTIONS AS IN FIGURE 4; INTERMEDIATE CASE OF SLIGHT CORRELATION

FIG. 6—DISTRIBUTIONS AS IN FIGURES 4 AND 5; EXTREME CASE OF RIGOROUS CORRELATION

must be chosen accordingly if we want to make the sum constant.

The resulting form of these artificial model distributions in the three cases mentioned is given in the following graphs. Instead of k another index κ was used to characterize the degree of correlation, ranging from 0 to 1; its meaning will be defined in §8. Figures 4 to 6 show the ellipses for (S_2+L_2) drawn for 6 equidistant values of μ during half a lunation. (In the following half of the month the same cycle would prevail.) The graphs do not give the probable ellipses which would correspond to the amounts of scattering assumed, but proportionally reduced ones, with axes 0.171 times smaller; this means that these ellipses would contain two per cent of the total number of points comprised in the whole cloud.

Figures 7 and 8 give the direction-angle θ_d and the total squared standard deviation M_d^2 as functions of λ. Note that to λ ranging from



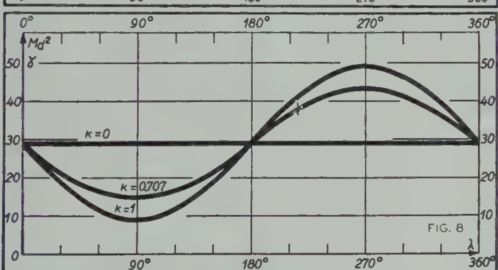


FIG. 7—DIRECTIONAL ANGLE θd FROM FIGURES 4 TO 6 REPRESENTED AS FUNCTION OF LUNAR AGE (λ) AND CORRELATION (κ); PERIODICITY ABOUT WEEKLY IN CASE OF NO CORRELATION BETWEEN S AND L—SEMI-MONTHLY FOR COMPLETE DEPENDENCE; MIXED FOR INTERMEDIATE STAGE

FIG. 8—TWO-DIMENSIONAL STANDARD DEVIATION M_d^2 FROM FIGURES 4 TO 6, REPRESENTED AS FUNCTION OF LUNAR AGE FOR THE THREE DEGREES OF RELATEDNESS BETWEEN L AND S

0 to 2π corresponds one-half lunation so that the periodicity of the parameters is either weekly (for θ_d, if $\kappa=0$), or mixed weekly and biweekly, predominantly the latter, (for θ_d if $\kappa\neq 0$), or merely biweekly (in the case of M_d^2, for $\kappa\neq 0$). The case of $\kappa=0$ is interesting in so far as M_d^2 remains constant, but not so the ratio of axes, which suffers a slight periodic change. As will be seen, the effect of κ on the ellipses is rather strong. Nevertheless, a more detailed examination of the reliability which can be attained in the analysis of empirical geomagnetic data will demonstrate that large numbers of points in each distribution would

be required if we wanted to reduce the sampling errors of the characteristic parameters so far as to make them decidedly inferior to the periodic oscillations represented here in the graphs.

§8—*Conclusions for practical application*

Suppose a series of observed distributions of the kind just described to be given. Our problem is then, in contrast to the procedure of the foregoing sections, to determine the parameters of distributions a and c as well as the factor k, by analyzing the parameters of d as funtions of λ. This is possible in the following way: If (S+L) has really the structure assumed in our model the unknown parameters θ_a, M_a, ϵ_a, θ_c, M_c, ϵ_c, and k will be contained implicitly in d according to equations (8.1) and (8.2).

$$M_d^2 = M_a^2[1+k^2-2k \sin(\lambda-\psi_0)]+M_c^2 \tag{8.1}$$

which results from (6.1) and (5.26), and

$$N_d \equiv 2r_d\sigma_x\sigma_y = A_a[\sin 2\theta_a - 2k\cos(2\theta_a-\lambda+\psi_0) - k^2 \sin 2(\theta_a-\lambda+\psi_0)] + A_c \sin 2(\delta_c-\lambda) \tag{8.2}$$

The last equation may be arrived at by inserting θ_b from (5.2) in (6.4), substituting, moreover, $(\Pi_b^2/\log_e 4)$ for M_b^2 in the same equation, and introducing, finally, $(\delta_c-\lambda)$ for θ_c [see (4.1)]. The definition for the values A is given in (6.3), while for deriving A_b from A_a it should be observed that

$$Q_b = Q_a \tag{8.3}$$

a relation which follows from (5.27). (8.1) and (8.2) can be written as sums of periodic functions of λ and 2λ, namely

$$M_d^2 = a_0(M_d^2) + c_1(M_d^2)\sin(\lambda-\psi_0) \tag{8.4}$$

$$N_d = a_0(N_d) + c_1(N_d)\sin(\lambda+\phi_1) + a_2(N_d)\cos 2\lambda + b_2(N_d)\sin 2\lambda \tag{8.5}$$

where

$$a_0(M_d^2) = M_a^2(1+k^2)+M_c^2 \tag{8.6}$$

$$c_1(M_d^2) = 2kM_a^2 \tag{8.7}$$

$$a_0(N_d) = A_a \sin 2\theta_a \tag{8.8}$$

$$c_1(N_d) = 2kA_a \tag{8.9}$$

$$\phi_1 = -(2\theta_a+\psi_0+90°) \tag{8.10}$$

$$a_2(N_d) = -k^2A_a \sin 2(\theta_a+\psi_0) + A_c \sin 2\delta_c \tag{8.11}$$

$$b_2(N_d) = +k^2A_a \cos 2(\theta_a+\psi_0) - A_c \cos 2\delta_c \tag{8.12}$$

Now the empirical M_d^2 and N_d found as functions of λ may be subjected to harmonic analysis, which gives us numerical values for the left-hand portions of equations (8.6) to (8.12). So the system may be solved for each of the unknown values on the right hand. In this way we obtain indeed from the observed distributions representing the total (S+L)-variability those for the solar and the lunar components separately.

The factor k may be interpreted in the following way: Equation (8.6)

represents the average of scatterings for the final distributions. In it two portions may be distinguished as in (8.13) and (8.14).

$$M_S^2 \equiv M_a^2 \tag{8.13}$$

$$M_L^2 \equiv k^2 M_a^2 + M_c^2 \tag{8.14}$$

The first of these two equations gives the part contributed by S to the total variability, the second that of L. M_L^2 for its part may be divided into the portion $k^2M_a^2$, which is due to the correlated part of lunar variability, and the independent portion M_c^2. We suggest now to define an index κ^2 as the ratio between the part of M_L^2 mentioned in the first place, and the total M_L^2; κ might be called an index of correlation between S and L. We have thus

$$\kappa = kM_a/\sqrt{k^2M_a^2+M_c^2} \tag{8.15}$$

If M_c is zero, and therefore the whole variability of L restricted to the distributions b described in §5, we have $\kappa=1$. On the other hand, to make vanish the part of M_L^2, contained in b, k must vanish too (since $M_a \neq 0$), so that in this case $\kappa=0$. Theoretically κ may also become negative, though it is not very probable that there exists a relation of this kind between S and L.

§9—*Outlook on numerical computations*

A practical attempt to apply the suggested method to observed data shows that rather large series of values would be necessary to decide whether the model of (S+L) corresponds in its structure to physical reality. The Fourier coefficients of (S_2+L_2) on individual undisturbed days ($C \leq 1.1$) from Batavia for east component, southern summer, 1906-29, were taken and subjected to statistical analysis, using data which had been computed for the paper [1]. They were now corrected for mean seasonal change, adjusting each pair of coefficients individually; thus the distributions calculated from the present values will be somewhat different from those published in the former paper. This measure was taken because it had been seen that the differences between the distributions for successive lunar ages μ were very small and affected by relatively big sampling errors; so the attempt had to be made to free those harmonic coefficients from any disturbing influence even at the price of considerable computational work.

Only days with sunspot-number $R=0$ were taken, but a more complete program including all groups of sunspottedness is now under way, since the present provisional results seem somewhat doubtful. In order to avoid the least slight deformation due to the method of calculation, the original graphical procedure described in [1] was abandoned in favor of direct numerical computation of the characteristic parameters of the distributions. For this purpose it was necessary to transform a great part of the 448 pairs to the new time-scale introduced at Batavia in 1920; this task was facilitated considerably by the use of a nomograph which will be described in a future note.

The present attempt is limited to the semidiurnal part of (S+L) because it was assumed that in the diurnal wave the effect of sampling errors would still be greater, as may be concluded from the more irregular distribution of the partial centers for the different μ-groups in the hexagonal scheme for (S_1+L_1).

Table 1 gives the characteristic parameters as obtained from the new computations; for each Moon-phase μ the corresponding angle λ is indicated as defined by (3.12). Next follow the values of M_d^2, then $N_d = (2r_d\sigma_x\sigma_y)$, both in units of γ^2, and finally the number n of points contained in each distribution. Because of quasipersistence these already insufficient numbers must still be reduced to "effective" numbers of about 50 for each group if we want to judge the statistical significance of the conclusions.

TABLE 1—*Characteristic parameters for elliptical distributions of harmonic coefficients,* (S_2+L_2), *Batavia, Y for southern summer, 1906-29,* $C \leq 1.1$

$\mu=$	0.5	2.5	4.5	6.5	8.5	10.5
$\lambda=$	18°	78°	138°	198°	258°	318°
$M_d^2=$	22.6	20.7	28.2	21.7	25.1	39.7
$N_d=$	−4.40	−2.49	−4.91	−0.81	+4.24	+4.42
$n=$	82	67	73	72	76	78

As will be seen, M_d^2 shows a quite irregular behavior, far from being a simple semimonthly sine-wave as should be the case according to our model, independently of κ. This discrepancy is no doubt largely a consequence of sampling effects. The semimonthly portion contained in the variation of M_d^2 has, however, a phase which corresponds approximately to that stipulated by our theory; in fact, this wave attains its maximum for about $\mu=10.2$, while equation (8.1) would have given $\mu=9.5$. In other words, the two-dimensional scattering of the distribution is indeed greater, in the average, in groups of days when L_2 and S_2 run parallel.

The periodicity of N_d is evidently simpler and more clearly semimonthly, but there is no reason for assuming that this parameter is obtained with greater relative security than M_d^2. The numerical application of the procedure described in the foregoing section gives thus, as is seen, still doubtful results. It seems certain, however, that L_2 is correlated with S_2 in a relatively small degree, and its scattering is stronger than that of S_2. It is to be expected that the analysis of more complete data now under way will permit us to emphasize these statements, which are consistent with the results of Bartels and Johnston published in [2].

The author is greatly indebted to Professor J. Bartels for many valuable discussions on the subject, and equally to Dr. J. A. Fleming for his constant interest, manifested also by concrete help granted by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, for part of the basic numerical calculations.

REFERENCES

[1] O. Schneider, Veröff. Met. Inst. Univ. Berlin, **1**, No. 3, 1936.
[2] J. Bartels and H. F. Johnston, Terr. Mag., **45**, 269-308 (1940).
[3] J. Bartels, Terr. Mag., **37**, 291-302 (1932).
[4] G. U. Yule and M. G. Kendall, An introduction to the theory of statistics, 11th ed., London, 1937, chapters 11 to 16.
[5] O. Schneider, La variabilidad de la oscilación lunar del geomagnetismo (to be published in 1941 in Buenos Aires).
[6] Ad. Schmidt, Erg. magn. Beob. Potsdam 1922, Veröff. Preuss. Met. Inst., No. 328.
[7] J. Bartels and G. Fanselau, Zs. Geophys., **13**, p. 311-328 (1937).
[8] J. Bartels, Beitr. Geophys., **28**, 1-10 (1930).

DIRECCIÓN DE METEOROLOGÍA, GEOFÍSICA E HIDROLOGÍA,
Buenos Aires, Argentina

THREE-HOUR-RANGE INDICES, K, FOR TWELVE MAGNETIC OBSERVATORIES, JULY TO DECEMBER, 1940, AND SUMMARY FOR 1940

By H. F. Johnston

K-indices from 12 magnetic observatories for the second half of 1940 are published herewith. Those for the first half of 1940 were published[1] in the issue for June, 1941, of this Journal and the indices from the seven American-operated observatories for the year 1940 were published[2] in the issue for March, 1941, of this Journal. In accordance with the wishes of Dr. J. Bartels, Director, Geophysikalisches Institut, Potsdam, who is Chairman of the Committee on Three-Hour-Range Index, the text of the circular letter of January 20, 1940, from Dr. J. A. Fleming, President of the International Association of Terrestrial Magnetism and Electricity, sent to all directors of magnetic observatories, is given as follows:

"At its assembly at Washington in September 1939, the Association of Terrestrial Magnetism and Electricity adopted a resolution as follows:

"Three-hour-range-index—The Association resolves:

"(*a*) That the cooperation of magnetic observatories be sought for a three-year period in an international trial-scheme for the provision of three-hour-range indices (K) to characterize the variation in the degree of irregular magnetic activity throughout each day, especially in order to meet the requests made by the International Union of Scientific Radiotelegraphy and other bodies for information concerning the magnetic activity more detailed than the present daily magnetic character-figures, and that this trial-scheme should, for the period 1940 to 1942, replace the scheme for a numerical character-figure.

"(*b*) That a Committee on Three-Hour-Range Index be appointed to organize the provision of these indices with special regard to speedy publication.

"(*c*) That the financial provision made during the past three years for the preparation and publication of the international daily magnetic character-figures be continued.

"(*d*) That the financial provision made during the past three years for the characterization of magnetic activity other than by daily magnetic character-figures be continued.

"The Committee on Three-Hour-Range Index (K; Indice trihoraire; Dreistundenindex) consists of Bartels (Chairman), van Dijk, Egedal, McNish, Stagg, and Sucksdorff. Reprints of two papers [*a*] 'The three-hour-range index measuring geomagnetic activity'[3] and [*b*] 'Main features of daily magnetic variations . . .'[4] are mailed under separate cover.

"The principles and the practice of scaling K are described in [*a*], which gives values of K for January to June, 1938, derived from records obtained at Niemegk, at the Huancayo and Watheroo observatories of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and at the five observatories Sitka, Cheltenham, Tucson, San Juan, and Honolulu, of the United States Coast and Geodetic Survey. This work is being extended to cover the years 1937 to 1939.

"As international cooperation in measuring geomagnetic activity, the Association asks all observatories, effective January 1, 1940:

"(1) To *continue* the characterization of Greenwich days (scale 0, 1, 2) exactly as heretofore, and to send these character-figures to De Bilt.

"(2) To *discontinue* numerical character HR_H, ZR_Z, etc.

"(3) To *introduce* the scheme of the three-hour-range index.

"For reasons set forth in detail in paper [*a*], the following procedure for choosing the scale for K at your Observatory is recommended: It is suggested you select a *tentative* scale from Table 2 of the reprint [*a*], and designated by the lower range-limit

[1]Terr. Mag., **46**. 239-244 (1941).

[2]Terr. Mag., **46**, 95-117 (1941).

[3]Terr. Mag., **44**, 411-454 (1939).

[4]Terr. Mag., **44**, 455-469 (1939).

for $K=9$ given in Table 1. Please measure K, with this tentative scale, for the following *test-intervals* from the year 1938: January 1938 (full month); March 15 to 20; April 16; June 22 to 24. If, on comparison with the published values, your K-values seem to be consistently too low or too high by more than one unit, please try one of the other scales published in reprint [*a*]. If you have magnetograms of different sensitivities, use the most sensitive ones to get the best values for $K=0$, 1, and 2. For assigning $K=9$, the record need not be complete for the interval, provided it is certain that the limiting range was surpassed in at least one element.

"The preparation of a diagram showing, for your Observatory, the 'main features of daily magnetic variations' similar to those published on pages 456-463 of reprint [*b*], will be helpful to you in assigning K; when plotting these daily variations, it is desirable to use the same relative scale of ordinates to abscissae as in reprint [*b*] where the scale for two gammas was chosen equal to that for one hour.

"We find that to measure and check K for a single month requires not more than 90 minutes; this is not more than the time required to determine the numerical character-figure for a single month. For covering the whole Earth, data from isolated observatories will be most useful; but even where several observatories are located close to each other, they might wish to participate in the program in order to get a good measure of activity for their own use.

"At the beginning of this trial-period, please send all correspondence and data on K directly to the undersigned. Please state whether you are willing to cooperate and send the K-data for the test-intervals of 1938, with your opinion whether the tentative scale is satisfactory. Please give also the scale-values of the records used, to the nearest tenth gamma per millimeter. When the K-scale for your Observatory will have been definitely adopted, please send monthly K-data, beginning with January 1, 1940.

"In inviting you to cooperate, I express the hope that the new index will prove to be a valuable supplement to the International Character-Figure, and that K will be a basic measure of solar (presumably corpuscular) influences on the Earth, useful in geomagnetic investigation as well as in correlation-studies with ionospheric, solar, and other phenomena."

TABLE 1—*Tentative lower range-limit in gammas for a K-index of 9 for magnetic observatories*

300		350	500	600	750
Otomari	La Quiaca	Auhof	Witteveen	Sloutsk	Dombås
Maj-tun	Vassouras	Ógyalla	Abinger	Rude Skov	Eskdalemuir
Tashkent	Apia	Nijnedewitzck	Srednikan	Agincourt	Lovö
Ksara	Kuyper	San Miguel	Niemegk	Huancayo	Stonyhurst
San Juan	Pilar	Coimbra	Manhay		
Teoloyucan	Tananarive	Tortosa	Jakoutsk		
Helwan	Mauritius	Stepanovka	Nantes		
Zinsen	Cape Town	San Fernando	Chambon-la-Forêt		
Kakioka	Toolangi	Zouy	Cheltenham	1000	1500
Tsingtao		Tucson	Sajmistsche		
Honolulu		Toyohara	Fürstenfeldbruck	Sodankylä	Godhavn
Dehra Dun		Doucheti	Regensberg	Lerwick	Baie Tichaja
Zô-Sè		Karsani	Sverdlovsk	Ouellen	Tromsö
Au Tau		Watheroo	Wyssokaya	Sitka	Abisko
Alibag			Doubrawa		Cap Tcheluskin
Antipolo			Amberley		Matotchkin Shar
			Orcadas		Dickson
					Meanook

From correspondence with some of the collaborating observatories, it appears that some question has arisen as to the precise quiet-day (S-) curve which should be used in measuring K-variations. An examination of the magnetograms for international quiet days shows marked differ-

ences, in as short a period as 40 to 50 days. Quotation is made from a letter by Dr. Bartels on this subject.

"It appears that the quiet-day curves may change their amplitude and form quite appreciably from day to day. If the curve for a particular day, though smooth, differs much from the average S-curve for the particular month—for example, if it is a straight line as if S did not exist—one may call this curve abnormal as far as S is concerned, but this fact in itself is not a sign of geomagnetic disturbance, if this expression is limited to the effect of *corpuscular* radiation from the Sun. So, since the K-index is designed to measure the effects of corpuscular radiation, the K-indices are all zero on a day during which the magnetic curves are straight smooth lines. There is an intentional difference, in that respect, from the practice adopted by several observatories for reporting magnetic character-figures.

"The flexibility which is thus introduced in the determination of S requires more attention and experience on the part of the observer. However, I am convinced that, by paging through the records of quiet days, one may easily arrive at a satisfactory distinction between the variability of S and the K-variation, including, of course, the typical daily variation in disturbed days."

Captain N. H. Heck reports that a gage for measuring K has been devised which is superior to that described on page 413 of the third reference.[3] The scales for each element are placed on one piece of cleared photographic film, about seven by ten inches in size. A common base-line is ruled across the base of the sheet and the scales for each element appear as successive horizontal lines about one inch long above the base-line. The horizontal lines are marked 0, 1, 2, ... 8 and are ruled at the appropriate distances from the common base-line to give the limiting ranges for each of the K-indices as marked. The assignment of K for any particular interval is much facilitated and, since the gage is a single one, quick check can be secured of whether the most disturbed element has been used in assigning the index. Such a gage also assists in ensuring that the gage is kept vertical since the base-line of the gage can be kept parallel with the base-line on the magnetogram.

TABLE 2—*Contributing observatories*

Observatory	ϕ	λ	Φ	Ψ	Lower limit $K=9$	Scale-value		
						D	H	Z
	°	°	°	°	γ	γ/mm	γ/mm	γ/mm
Lerwick	60.1	1.2W	62.5	−23.6	1000	4.2	4.2	5.3
Dombås	62.1	9.1E	62.3	−23.6	750	7.1	5.9	5.9
Meanook	54.6	113.3W	61.8	+17.2	1500	4.8	9.2	10.7
Sitka	57.0	135.3W	60.0	+21.4	1000	4.5	6.7	8.5
Eskdalemuir	55.3	3.2W	58.5	−20.4	750	4.5	3.9	6.0
Rude Skov	55.8	12.4E	55.8	−20.6	600	4.9	10.1	10.0
Agincourt	43.8	79.3W	55.0	+ 3.6	600	5.8	4.8	10.0
Witteveen	52.8	6.7E	54.2	−19.3	500	5.2	5.2	5.2
Abinger	51.2	0.4W	54.0	−18.4	500	4.9	4.5	4.0
Niemegk	52.1	12.7E	52.2	−18.8	500	2.5	2.5	2.5
Cheltenham	38.7	76.8W	50.1	+ 2.4	500	5.3	2.7	4.0
San Fernando	36.5	6.2W	41.0	−13.6	350	5.3	3.2	...
Tucson	32.2	110.8W	40.4	+10.1	350	7.8	3.0	4.1
San Juan	18.4	66.1W	29.9	− 0.7	300	8.0	3.1	5.6
Honolulu	21.3	158.1W	21.1	+12.3	300	8.5	2.9	3.1
Zô-Sè	31.1	121.2E	19.8	+ 2.2	300	...	1.8	...
Huancayo	−12.0	75.3W	− 0.6	+ 1.3	600	8.6	2.1	4.3
Cape Town	−33.9	18.5E	−32.7	−13.7	300	3.9	5.2	7.9
Watheroo	−30.3	115.9E	−41.8	+ 1.3	350	7.2	2.5	3.4

Table 3--Three-hour-range indices, K, July to December 1940

July 1940								
	1	2	3	4	5	6	7	8
Le	4411 3221	0112 2121	2222 3337	7432 3335	5222 3333	4322 3232	2112 3232	1211 2222
Do	3212 1120	0001 1212	1122 3238	7433 3336	5222 3344	3323 3232	2002 2330	1100 1212
Me	2210 0012	1100 0011	2233 3224	4466 2335	4334 3223	3342 3232	1010 2222	1111 2113
Es	3221 3331	1121 2222	2232 3335	5333 3334	3232 4343	4323 4332	2112 3231	1111 2223
RS	3110 2120	0011 1122	2122 3344	4333 3334	3221 3334	3222 4231	2011 3331	2100 1113
Ag	5211 1231	1100 0223	2221 3244	5433 1345	5242 3233	4322 2343	2011 1212	2000 2224
Wi	4212 3330	1112 2310	2322 3344	4333 3324	3133 4344	2333 4333	2212 3331	1000 2214
Ab	4212 2231	1211 1222	1233 3444	4333 3334	3221 4343	3422 4332	2222 3332	2110 2324
Ni	4201 1230	1001 1221	1212 3344	4333 3334	3211 2344	3322 3332	1111 2331	2010 1213
SF	2324 2141	0122 3313	2132 3233	5235 4335	4113 3444	4313 3233	3101 2332	2222 1125
ZS	3323 2231	1122 1112	1432 3225	4543 3334	3342 3232	3323 3223	3232 1221	2123 1123
CT	2111 0010	0011 0100	0001 2233	3332 3124	2121 2033	2212 0230	0000 1121	1000 1002
	9	10	11	12	13	14	15	16
Le	2321 3233	4443 4333	4431 2223	1211 2121	1225 6555	3533 3333	4422 3332	3322 2322
Do	2322 4332	4444 5333	3422 2223	2212 2121	1025 7546	4534 4433	4323 4332	2222 3322
Me	3244 2223	3776 6323	3334 1122	2311 1120	2227 7544	3565 6323	4443 4333	3333 1222
Es	2322 3333	3443 4423	3322 2322	2221 2121	1235 6544	2433 3332	3312 3332	3222 2322
RS	2312 4232	4344 4334	3321 2222	2212 1111	2226 7544	3433 3323	3332 3332	2222 2222
Ag	3432 2334	4564 3334	3533 1223	3301 1131	2135 6544	4554 3323	4432 3333	4323 2222
Wi	2332 3343	3345 4334	2322 2222	1111 1111	0225 6544	3433 3332	2323 4332	1133 2322
Ab	3422 4343	4443 4424	3432 3322	2312 2121	1236 6643	3433 3433	3322 3432	3312 3323
Ni	2312 3333	4334 4333	3321 1222	2212 1121	1225 6643	3523 3333	3322 3332	2211 2222
SF	3422 3344	4353 3422	4431 0231	2332 2231	2255 6545	4434 2442	2233 4422	2341 1102
ZS	4322 3334	3444 5233	3343 2222	2323 1122	3343 6533	3433 3222	3232 2222	2234 1323
CT	2222 2222	3321 3213	2212 2111	0211 0000	1023 6344	2322 2312	2011 1120	1020 0001
	17	18	19	20	21	22	23	24
Le	2211 1320	0111 1112	1111 2222	1111 2122	1122 2333	1342 3332	2111 2223	2322 3213
Do	1111 1310	1100 1011	1101 2222	0011 1222	2113 2333	2233 4332	3212 3222	2323 2323
Me	2122 0111	1101 1011	2101 0122	1110 1012	2026 3223	1475 3212	3211 2211	2435 1212
Es	2111 1311	0111 2111	1111 2223	2111 2222	2122 2332	1343 4332	3122 3222	2322 3323
RS	2121 2300	0101 1002	1100 2122	1111 1121	2113 3332	1242 4332	2211 3222	2333 3223
Ag	2220 0110	1001 1012	2100 1123	1210 1133	2123 2223	2453 3223	2101 1223	2333 1223
Wi	2111 2300	0001 1001	1110 2222	1111 1222	1213 3333	2343 3233	2212 2322	2333 3323
Ab	2211 2311	1111 1111	2311 2223	2111 1222	2212 2332	2343 4332	3111 3323	2332 3224
Ni	2110 1310	0101 1001	1111 2223	0110 1121	2112 1232	2232 3332	2201 2222	2323 2223
SF	2121 2321	1010 2211	1210 2123	2120 3123	2232 3343	2444 4321	3201 3332	2343 1114
ZS	1123 1210	1122 1101	3323 1123	2221 2222	2234 3232	3442 3321	2342 1212	2434 2222
CT	0101 0000	0000 0000	1010 0012	0001 1010	2023 1122	0232 2201	2012 0001	0222 1003
	25	26	27	28	29	30	31	
Le	3222 2311	3211 2201	1001 1211	2112 2112	1212 2233	2322 3342	4332 2322	
Do	2322 2321	2202 1201	0000 1210	2102 2000	1202 2032	2112 4333	4333 3433	
Me	2454 0112	3232 0101	1111 1111	1024 1101	1111 1133	3323 3333	3664 5233	
Es	3233 1322	2212 2211	2111 1211	2112 2212	1111 2233	2323 4443	3333 3332	
RS	3222 2211	2111 2200	1011 0110	1002 2102	1221 1143	2322 4342	3332 2333	
Ag	3343 2212	3322 1010	1210 2121	2223 2222	1211 1144	2323 3354	4444 3243	
Wi	3323 3311	2111 2200	0000 1111	1122 2112	1101 2344	3322 4443	3334 3333	
Ab	3332 2312	3311 3211	1111 1311	2112 3212	1222 2243	2333 4443	3433 3333	
Ni	3223 1312	2211 1201	0001 1200	1102 2201	1222 1143	2322 4343	3322 2333	
SF	4333 0212	3232 2300	1201 1322	3223 2121	1311 3242	3434 4454	4534 3332	
ZS	2434 1212	4212 1202	1212 1212	3323 1210	2322 3122	2434 2333	3343 3322	
CT	3132 2101	1000 0000	0000 0100	1002 1201	1111 2232	1232 2232	3332 2112	

August 1940								
	1	2	3	4	5	6	7	8
Le	5412 2323	2122 2341	2333 6533	3222 2231	2213 3323	3222 3334	4113 3441	4432 3212
Do	5302 2323	1002 2342	3223 7532	3222 1100	0113 4334	3223 4343	2123 3431	3223 3313
Me	4300 1213	0011 1242	2376 6632	2255 1112	2314 3233	3355 4223	3256 4431	3366 3112
Es	4213 2323	1122 2352	2333 6643	3132 2331	2213 3323	3233 3444	2122 3431	3232 3202
RS	4212 2123	1111 2351	2434 6542	3222 0131	1213 3334	3223 3344	2222 3441	3233 3213
Ag	5311 1233	1113 1253	2355 4333	3433 1332	3413 3323	3453 3333	2234 3331	3344 2223
Wi	4312 2222	2122 2352	2444 5543	4332 2231	2212 3334	2233 3354	2123 4431	3233 3312
Ab	4312 2223	2112 3353	2333 6643	4233 1332	2323 3333	3243 3455	2223 3431	3233 3313
Ni	4312 2223	1111 2352	2233 6642	3222 1132	1213 3324	3223 3344	2123 3430	3223 2213
SF	5411 1324	1021 1363	3334 4642	3223 2232	2233 4331	4232 3255	3345 4441	3314 2312
ZS	5433 2322	2242 2353	2354 4641	2232 2112	2322 3222	3334 3233	3233 3432	3154 2203
CT	4311 2212	0012 1241	2223 3421	2213 0011	0111 1022	2122 1144	1032 3330	2122 2001
	9	10	11	12	13	14	15	16
Le	3335 4474	3122 2321	3223 3334	3331 2333	3212 2221	1222 2212	2121 2210	1121 1110
Do	3335 5476	3113 3411	3222 3443	2321 2323	4212 2221	1222 2213	1000 0100	0010 0120
Me	2357 5333	1134 2211	2345 5433	3534 4322	1322 2211	2323 3101	1010 1100	0130 0010
Es	2344 4462	2123 3421	3233 3333	2333 2322	3222 2321	1232 3222	2011 2210	0021 2221
RS	3344 4463	3123 3321	3222 3343	2222 2213	3222 2211	1322 2213	1100 1000	0020 0010
Ag	2456 5466	2223 2321	4434 2343	3532 2322	3332 2212	0434 2112	2120 1122	1120 1122
Wi	2343 4454	2032 3411	3233 3343	3332 3333	3222 2212	1322 3212	2010 0000	0010 0110
Ab	3344 4463	3223 3422	3332 3434	2331 2323	3222 2322	1332 3222	2111 1121	1121 1121
Ni	3234 4463	3212 3321	3222 3343	2212 2215	3211 1312	1311 2112	1110 0000	0010 0010
SF	3455 4564	3232 3212	4331 4323	3343 0223	3231 1221	1322 2122	3122 2210	1100 0221
ZS	2435 5233	3323 3311	3332 3322	3443 3212	2331 1212	3333 3211	2220 2013	1231 0010
CT	1025 3352	3111 3301	2222 3323	2123 1201	1121 2011	0111 3001	1000 1000	0000 2111
	17	18	19	20	21	22	23	24
Le	1002 1211	0012 3553	2011 3433	2322 2321	2112 3113	2112 2342	2212 2221	1012 2110
Do	0001 0110	0002 3533	1020 3423	3233 3330	2202 3223	3002 2442	2112 2221	0000 1000
Me	1000 0101	1002 3332	1011 2322	3533 3222	1211 2221	1011 2221	2220 0021	1000 0110
Es	1111 1211	1111 3433	2011 3323	3322 3321	2212 3223	3012 2442	2211 2221	0012 1210
RS	0010 1111	0101 2434	2011 2333	2323 3331	2102 2213	3112 1442	3211 1121	0001 1000
Ag	1012 2354	1122 3444	2112 3433	3422 2311	2212 2122	2222 2322	2221 1121	0000 2221
Wi	0011 2111	0022 2443	2012 3333	3323 3231	2212 2223	3112 2342	2211 2121	1000 0000
Ab	1111 1212	1111 2534	3112 3433	3333 3331	2202 3223	3222 2442	2111 2232	1111 1000
Ni	1000 1112	1101 2434	3111 2333	3323 2230	2201 2223	3122 1442	2111 2121	1000 0000
SF	2002 0111	1111 1455	2233 4434	3422 3420	2300 3122	2222 3342	3200 3131	1000 3200
ZS	3322 0012	3334 4434	2331 2334	3342 2323	3212 2233	3443 4433	1322 2233	1220 1002
CT	1001 1100	0001 2543	2221 2331	2233 2211	2201 1222	2122 3341	1110 1110	0011 0000
	25	26	27	28	29	30	31	
Le	0011 1223	2212 3235	4321 2322	3322 2122	3112 3211	1011 1122	2012 2223	
Do	0000 1224	2212 3335	4322 2313	3422 3232	3223 4221	2001 2232	1002 2224	
Me	0000 0112	2101 2234	3432 1223	2344 1112	3133 3112	1000 0122	2111 1213	
Es	0111 2233	2313 3345	3322 3323	3322 3222	3222 3212	1102 2223	2122 2223	
RS	0000 1124	2313 3235	4332 2223	3322 3231	3212 3110	1001 2132	2111 2114	
Ag	0000 1133	2113 3345	3532 1323	4432 2223	4233 3222	1000 0222	2211 2223	
Wi	0001 1133	3312 3345	4322 2213	3322 2231	3122 4201	1001 2222	2012 3324	
Ab	1000 3233	3313 4346	3432 2323	4322 3232	3113 4222	2001 3223	2111 2224	
Ni	0000 0223	2212 3345	4322 2323	3322 2232	3112 3110	1011 1232	2001 1224	
SF	0002 2333	3302 2333	4422 3312	4233 1123	3124 3110	2211 2113	4113 1224	
ZS	1111 0223	3322 4334	3432 2323	3433 2222	3313 4111	2212 1213	2113 2223	
CT	0000 0011	1122 4335	2121 2201	2122 1010	2012 2000	0021 1012	1021 2002	

	1	2	3	4	5	6	7	8
Le	5533 5431	0122 3333	6333 3433	4233 2334	3322 2331	2212 3213	4553 3424	5223 3333
Do	5222 6521	0012 2344	6443 3445	5214 3334	3222 3331	2103 2213	4543 3425	3214 4321
Me	5557 7520	1225 4233	6345 5322	3146 3213	3323 3222	2334 3113	5767 4313	2235 4422
Es	3333 4321	0122 2333	3333 4334	4333 3324	3323 2321	2222 3213	4443 3424	2223 3322
RS	4333 4320	0022 2332	4433 3334	4233 2244	3322 2231	2222 2112	4432 3425	3123 4321
Ag	4444 4322	1223 3243	4343 3333	5335 2333	3434 3122	2323 2233	5545 4224	4323 4322
Wi	3344 4421	0122 3333	3433 3433	4222 2244	3322 2331	2202 2113	4443 3424	3213 3333
Ab	3333 4321	1112 3443	3433 4434	4332 2334	3322 2332	2122 3213	4443 3414	3224 4423
Ni	3323 3320	0022 2333	4433 3434	4311 1234	3212 2331	2102 1213	4322 3425	3223 3312
SF	3330 3432	1133 2243	4343 4434	5443 4323	3334 3230	1132 2313	4454 4324	4234 3332
ZS	4445 4433	2334 3233	3552 3333	4344 4234	2344 2322	3333 4213	4434 3423	3414 3422
CT	2133 4322	1013 3232	3134 2323	3122 2101	1122 2021	1100 1002	3212 3213	3123 3131
	9	10	11	12	13	14	15	16
Le	4423 2343	3110 1111	1001 2221	1112 2111	0011 2210	2212 2353	2322 3231	0112 4320
Do	4313 2354	2010 0001	0001 2201	1001 1121	0000 2210	2200 3343	2320 3331	0111 4320
Me	4425 3232	1110 0011	0002 1221	0021 1111	0000 1210	1200 1253	0432 3222	1230 3411
Es	3323 2343	1121 1111	0002 2321	1012 2111	1112 3320	2222 3353	1333 3231	1122 4421
RS	3423 2344	1010 0001	0000 2210	1101 2121	0000 2220	2210 3343	2322 3341	0121 4320
Ag	5433 2332	2200 0001	0002 2111	2111 1111	0001 1212	2310 2344	1532 3222	1331 3422
Wi	4422 2444	2110 0001	0001 1211	1001 1111	0001 2220	2212 3343	2232 2341	0111 3330
Ab	4333 3244	2220 1001	1012 2321	2111 2212	1111 3321	3321 3353	2333 3342	1221 4432
Ni	3322 1344	1011 0001	0001 2221	2111 1111	0000 1210	2211 2353	2321 3341	1211 4431
SF	4333 2244	2323 3000	0003 4232	1212 2000	0022 1320	4313 2464	1331 2431	2202 5430
ZS	3333 3233	1120 0001	1223 2222	2322 2211	1121 3311	2332 3453	3433 4323	2333 5422
CT	2111 2133	0020 0000	0022 0021	0001 1000	0010 1100	1000 2452	1221 2111	0111 4322
	17	18	19	20	21	22	23	24
Le	0012 0112	0011 1122	1011 1200	0122 4323	2223 3321	0012 3221	1001 0100	0001 0113
Do	0000 1112	0001 0022	0001 1000	0112 3432	2324 4320	0012 3232	1001 1010	0000 0013
Me	0000 0001	0000 1221	0000 1111	0111 3222	1125 5212	0024 2111	0000 1000	0100 0011
Es	0112 1112	0111 1112	1021 2101	1122 4422	2223 3311	1122 3121	1011 1011	1101 1113
RS	0001 1001	0001 0022	1011 1100	0013 3332	2323 3311	0012 3221	1000 0000	0000 0003
Ag	0000 1112	0001 1221	1101 1011	1112 3333	2223 3222	0023 2232	0000 1212	0100 0123
Wi	0001 1001	0011 0022	1011 1000	0012 3322	2223 3320	0013 3231	0000 1000	1000 0113
Ab	1112 1122	1021 1122	2111 2111	1123 4443	3234 3322	1123 3232	1111 2111	1201 1113
Ni	0010 1111	0011 0022	1010 1000	0122 3422	2223 3111	0012 3221	1000 0010	1100 0113
SF	0000 2222	1023 1212	2121 1202	1231 4533	3223 3222	2123 3231	1123 3201	1120 1004
ZS	1232 1112	1231 1022	2331 1103	2234 3233	3344 4422	2332 4332	2312 2112	3332 0121
CT	0110 0001	0032 1101	1112 1001	0023 3412	1123 2010	0013 3220	1022 1010	0011 0001
	25	26	27	28	29	30		
Le	2333 3444	2001 1686	9632 3456	5544 3453	3212 3232	1010 2143		
Do	3344 2444	1001 2595	9622 3567	6544 4464	4222 2243	1010 2253		
Me	2443 3332	1010 1664	5565 3444	3776 5443	2343 3321	1100 1122		
Es	3334 3444	2002 2564	6522 2454	4443 2453	2222 3242	2110 2143		
RS	2333 2434	1001 1665	6422 3465	4443 3553	2112 3133	1000 1143		
Ag	3442 2333	0001 0564	7633 2344	4575 3443	3332 2321	2000 1233		
Wi	3334 3444	2001 0674	5413 3454	4443 4553	2212 3332	2110 1253		
Ab	3434 3444	2111 1675	6432 3465	4443 3453	3222 4242	2111 2243		
Ni	3433 2444	1001 0675	6412 2465	4443 3553	2112 3132	1010 1143		
SF	4434 3544	2120 4776	6433 3465	4453 5454	2232 4143	2210 1243		
ZS	3434 3533	2230 1565	4424 3553	5445 4532	4233 4222	1322 1233		
CT	1104 2433	0100 1455	5412 2354	3322 3343	2023 2130	1001 1331		

	1	2	3	4	5	6	7	8
Le	4432 4791	1122 2333	1332 3353	4520 1222	3321 2200	1012 3335	5344 5686	6653 3466
Do	5312 5792	1122 3333	2332 3353	4500 0311	3202 2210	1002 3324	6443 5698	8742 3466
Me	4446 6553	2235 4332	1466 4232	5410 1101	2322 3310	1133 4222	4476 7644	5775 4443
Es	4322 4471	2122 2333	2232 3353	3321 2211	3311 2111	1113 3324	4454 4465	5543 3345
RS	4322 4472	1122 2433	1332 2453	4310 0321	2211 2210	1012 3314	4444 5576	5643 3355
Ag	4534 3572	2043 3323	1354 2333	4310 1121	2321 1221	2122 3323	3475 5456	5764 2344
Wi	4322 3462	1122 3433	2332 2454	4322 1311	2311 3210	0113 3425	4444 4566	5543 3444
Ab	4323 3552	2122 3423	3332 4453	4311 1311	3322 2111	1113 3425	4354 4465	5543 3346
Ni	4312 3451	1012 2433	1322 2453	4300 0301	2302 3100	1112 2424	4443 5476	5532 2345
SF	5442 3653	3223 2432	3343 4453	4402 1301	1233 2201	0114 3524	5463 5465	5543 2446
ZS	2334 4552	3233 3542	2243 4343	3222 1314	2321 3212	2224 3424	3455 5554	5434 4443
CT	4312 3543	2122 2333	1132 3352	3310 1100	1002 2200	0203 3433	4243 4553	4433 3436
	9	10	11	12	13	14	15	16
Le	5122 1122	0112 2233	3211 2114	3312 2214	1110 1101	0001 1111	1123 2322	2021 1342
Do	4002 2031	0002 2133	2200 2114	4322 2324	2221 1000	0000 1001	2233 2232	2012 2351
Me	3114 0111	0024 4112	2423 4110	2114 2211	1000 1111	0000 0100	1447 3111	0144 2221
Es	4122 2122	0112 3232	2221 2113	3223 2223	1121 2201	1001 1111	2233 3332	2122 2241
RS	4102 1022	0012 2043	2221 2104	4212 2214	1121 1000	0001 1001	1123 1332	2012 2451
Ag	3102 1131	0112 2223	2322 2122	2102 1223	1000 1011	0000 1021	1334 3233	0043 1231
Wi	4211 1012	0012 3244	2200 2213	4212 2214	1110 1000	0000 0010	1233 2332	1021 1351
Ab	4222 2122	1112 2133	3321 2114	3223 3324	2121 2111	1111 2111	2224 3332	2131 2351
Ni	4102 1121	0002 1033	2211 1104	4213 2214	1121 2000	0001 0011	1223 2332	2011 1351
SF	5131 2222	0124 3243	2321 2124	4204 2213	1111 2200	0023 3112	2333 4443	2033 4352
ZS	3222 2212	2333 3231	2122 4222	3123 3233	2222 2112	1221 1112	2343 4323	1233 4432
CT	3012 2111	0012 2021	2121 1103	1012 3301	1010 2210	0222 3201	2223 3322	0022 3442
	17	18	19	20	21	22	23	24
Le	1111 2113	2221 2233	2233 2243	2212 1124	2123 2354	2232 2111	0001 0100	0011 1100
Do	1000 2013	2222 2234	3213 1024	2123 2355	3233 2022	0000 0000	0000 0000	0000 0000
Me	1100 1102	1164 1123	2355 5222	2221 1113	2145 2333	2476 5121	0000 0010	0000 1110
Es	2112 2113	3232 2222	2333 3244	2222 2123	2223 2344	2233 3121	1001 0100	0001 1110
RS	2100 1113	2222 3233	2333 3243	3222 1114	2123 2444	3233 2021	0000 0000	0000 0000
Ag	1100 1022	1142 2133	1332 2233	3212 1123	2133 2233	2353 4221	0000 0210	0000 1120
Wi	2100 1013	2122 2223	2233 3244	2212 1014	3123 2343	3233 4210	0000 0000	0001 0000
Ab	2211 2213	3232 3333	2343 3244	2222 2124	3223 2344	2344 4121	1121 1110	1011 1100
Ni	2100 2013	2212 2233	2323 3243	3212 1124	3223 2444	3233 3021	0001 0000	0001 1000
SF	3110 0223	3241 1244	3344 5345	3222 2124	3325 2355	3245 4111	0223 1000	1012 2000
ZS	3221 2222	2353 2234	3354 3333	2323 1223	3234 3433	2553 3211	1220 0102	1221 1213
CT	3111 2203	2242 2134	2243 3343	1122 2222	0024 3344	1334 4010	0021 2100	0020 2100
	25	26	27	28	29	30	31	
Le	0001 2255	2122 3555	3322 2333	3212 2242	0312 1110	3211 1102	3111 1210	
Do	0001 2255	2123 4666	4323 3443	4212 2252	0311 2342	3200 0003	2201 1210	
Me	1002 3213	1114 5543	2355 5321	2355 2122	0211 2110	1220 1011	1155 1210	
Es	0012 3344	2223 4554	3322 3332	3212 3242	1322 2111	3211 1112	2122 2221	
RS	0002 2344	2124 4454	3323 3443	3212 3252	0311 1110	2111 1012	2101 1210	
Ag	1000 2234	2223 3432	3344 4222	4433 2332	1422 1210	3221 1121	3123 2210	
Wi	0022 2344	2234 5565	3223 3443	3223 2352	1311 1010	2211 1111	2202 2321	
Ab	1112 3455	3334 5555	3323 3443	3222 3352	1421 2111	3211 1122	3231 3221	
Ni	1002 2345	2123 4454	4212 3443	3202 1251	1301 1010	3200 0012	3101 1220	
SF	0001 5456	3445 6554	3334 3422	3303 3241	2320 0001	2222 2121	3232 3321	
ZS	2212 4455	4345 5653	3324 4432	2233 2341	2212 2222	2222 2012	3233 3312	
CT	1223 3345	2344 5543	2223 4331	2023 0131	1143 3000	1123 1201	1233 3321	

$^{\cdot\cdot}$Interpolated

Table 3--Three-hour-range indices, K, July to December 1940--concluded

November 1940	1	2	3	4	5	6	7	8
Le	2232 2220	1221 1102	2232 3233	3332 3666	5432 2232	2221 1232	2123 2112	2111 1121
Do	2223 2120	0122 0002	3222 2233	3332 3676	3313 2240	2200 1232	2222 2012	2000 0000
Me	0177 4211	0244 3100	2456 5211	1432 5333	1354 3110	2335 5101	0233 2100	0356 5300
Es	2232 2120	1222 1002	2232 2222	3332 3454	3423 3231	2222 2222	2133 3112	2110 1011
RS	2233 2120	0122 0002	2232 2233	3332 4554	3323 3231	2211 1232	2123 2111	2000 0010
Ag	1353 3220	1352 2011	3435 2122	1431 5433	3553 2120	4223 1010	2233 3111	2010 1111
Wi	2333 3220	1232 1002	3223 3333	2332 4554	3333 2241	2222 2232	2224 3112	2110 1001
Ab	2333 2230	1232 1102	3333 2133	3332 4454	3323 3241	2232 1232	2133 3112	2111 1011
Ni	2223 2130	0212 0001	3212 2022	3322 3454	4313 3230	2211 0232	2122 2012	2000 0001
SF	2343 3232	1213 1203	2443 2223	2342 5555	4424 3233	2220 2323	1135 4301	2003 3111
ZS	2454 4233	2243 3202	2234 4333	4243 5442	3434 3321	3232 2321	3332 3223	3111 2211
CT	1334 2330	3232 1101	1122 0122	1222 4444	3333 3233	0033 2122	0142 3211	1021 2000
	9	10	11	12	13	14	15	16
Le	1222 3333	2111 0000	1010 0002	3113 2347	7763 3321	3322 3224	2222 1224	4201 2444
Do	0122 3432	0000 0000	0000 0002	2023 3458	7762 3322	3323 3335	3313 2224	4200 0564
Me	0345 4210	0111 0001	0000 0001	0016 3333	6664 5322	2235 4222	2252 1212	3111 1333
Es	1231 3322	1111 1100	0011 1002	3123 3345	6553 3221	3323 3324	2222 1233	4211 2453
RS	0121 3332	1000 0000	1000 0002	2023 3446	5653 4422	3322 3325	3223 1233	4212 2554
Ag	1344 3330	1200 1120	0000 1112	2025 4335	7763 3322	3222 3243	3332 2333	3201 2433
Wi	1231 3423	1001 0000	0010 0003	2034 3345	6552 4422	3322 2224	2223 1234	4211 1544
Ab	1232 3322	1111 1101	1110 1102	3134 3346	4553 3332	3332 3335	3323 2233	4212 2553
Ni	0211 3322	1000 0000	0000 0003	3013 3345	4552 2322	3322 3325	3323 1233	4201 1544
SF	1332 3431	1102 1111	0011 2003	3135 4356	5542 3232	3232 4445	4332 1343	3221 3654
ZS	2443 3433	3112 0211	2221 1112	2236 4444	4453 4534	3433 4323	3333 3333	2332 3533
CT	1333 2331	0331 1100	0133 2002	2134 3346	3443 3433	2332 3333	2232 3333	1232 3543
	17	18	19	20	21	22	23	24
Le	2111 2454	3021 1012	1112 2111	0011 1225	5243 2126	3444 3155	3334 3132	1020 1114
Do	2101 1465	3021 1002	1001 2121	0000 0125	5224 3227	4444 3155	4334 4141	2000 1214
Me	1101 1333	1012 1000	1044 1101	0000 1113	2166 5203	2566 6224	2576 6211	0231 1210
Es	1101 2454	3121 2112	2112 2122	1011 1224	4343 2224	4443 3144	3334 2132	1021 1113
RS	1011 2464	3122 1002	1111 2111	0001 1234	5343 3025	4443 3155	3333 3142	1000 1114
Ag	1100 1443	2211 1012	2033 1221	0010 2324	4345 3225	3465 4243	2566 3221	1241 2111
Wi	1001 1454	3012 2013	1012 2011	0001 1235	4233 3224	4444 3255	3344 3142	1010 1134
Ab	1211 2455	3121 2112	2133 2222	1122 2334	5343 3225	4554 4255	3344 3231	1121 1124
Ni	1101 1464	3122 1013	1111 1122	1011 1234	5323 2125	3433 3055	3333 2141	1010 1124
SF	1221 2555	3131 1202	2033 3202	1133 3244	4443 3435	4444 5464	4453 3321	1030 1221
ZS	3222 2443	2222 3113	3343 3222	2332 3334	3464 4323	3555 5343	3334 5322	1232 2221
CT	2322 2433	2332 2111	1231 3212	1232 2323	3354 3224	2344 4243	3253 2221	0123 1221
	25	26	27	28	29	30		
Le	2114 7655	5433 3321	2111 2343	1111 1113	3333 5546	3312 2333		
Do	2014 4775	4422 3431	2112 2443	3323 3444	4333 6546	4402 3343		
Me	1046 7632	3477 4321	2033 4212	0101 2102	1565 6443	3334 3321		
Es	2124 5534	5342 3321	2122 2333	0112 1114	2334 4445	3322 2333		
RS	2124 6554	5433 3421	2111 3443	0111 2223	2444 5545	3222 3343		
Ag	2125 5533	4565 3321	3132 4212	1112 1223	2656 5435	5324 3322		
Wi	2234 6555	4443 3421	2112 3442	0011 2223	2433 4545	4323 2343		
Ab	3225 6545	5443 3421	2112 3343	0112 2114	3444 5545	4323 3434		
Ni	2124 6555	5432 3420	2011 3433	0111 1124	2424 5545	2222 3343		
SF	2135 6554	5554 3521	2011 4144	1002 1004	3445 5556	3333 3434		
ZS	1235 6554	4433 4523	2232 4433	1232 3224	2555 5534	3223 5322		
CT	1235 6543	3333 3421	1134 3123	0123 2202	1333 5344	2223 3222		

December 1940	1	2	3	4	5	6	7	8
Le	2222 2134	3323 3434	3213 2434	1211 2441	3221 1132	2101 1121	2110 0000	0000 0010
Do	2322 2234	4433 3554	3223 3444	2200 2440	3211 1242	2100 1031	2000 0100	0000 0020
Me	1345 2222	3437 4423	2115 4323	1233 4221	0442 1011	0112 0100	0001 0000	0000 0000
Es	2322 2233	3324 2334	3213 3324	1321 3332	3222 2222	2112 1121	2111 0000	0000 0000
RS	2222 2144	3324 3554	3224 3434	2212 3441	3212 1231	2211 0121	2011 0000	0000 0010
Ag	2533 2333	4435 3324	4103 3323	2443 3331	2431 1112	1312 1121	3000 1210	0000 1221
Wi	2223 2244	3324 3455	3214 4445	1222 3442	3221 1232	2101 1121	2110 0000	0011 0010
Ab	2322 2233	4324 2444	3213 4465	2322 3442	3322 2232	2211 1122	2111 1101	1100 0010
Ni	2212 2244	3314 3544	3213 3434	2201 3441	3211 1232	2200 0121	1000 0000	0000 0010
SF	2333 3233	4335 4434	4324 4434	2231 3441	2233 2332	2222 1111	1213 3110	0011 0110
ZS	2232 2331	3324 4432	2215 3422	2223 4331	2322 3321	2222 2122	1322 1101	2212 1022
CT	0142 3222	3224 3333	1113 3322	2213 1231	1122 1121	0332 2210	0112 1000	0221 0100
	9	10	11	12	13	14	15	16
Le	0122 2113	1212 1332	1012 0224	3121 1322	3213 1232	3112 2443	2111 3334	3212 1121
Do	0232 3214	2202 2422	2111 0325	3122 1433	4122 1232	3122 1232	2201 3444	3222 2232
Me	1354 5110	1222 1432	0121 0113	2132 2312	3135 1111	1125 5442	1001 3332	1134 3211
Es	1222 3112	1222 1422	1112 1223	2122 2322	3223 1122	3122 3444	2111 3333	3213 2221
RS	0122 3114	1212 1422	2011 0224	3222 2422	4223 1232	2122 3554	2201 3443	3323 1121
Ag	1323 3231	1212 1331	1220 1113	2121 2331	3212 2131	2214 4433	1001 3334	2345 2211
Wi	1233 4214	2302 2421	1111 1224	3112 2421	4213 1133	3113 3443	2111 3344	4222 2212
Ab	2233 4213	2332 1432	2112 2324	3222 2332	4323 2232	3122 3544	2111 3334	3223 2321
Ni	1222 3213	1302 1421	2111 0224	3122 2422	4222 1232	3112 3454	2101 3444	3212 2221
SF	2224 4221	1332 1631	1213 0124	2132 2422	2234 2212	3233 4654	2143 4444	2234 2211
ZS	2352 4323	3423 2531	3333 1233	2332 3423	3334 1322	1343 3342	3212 3333	3333 2311
CT	3223 4321	0313 3421	1233 2002	2331 2321	1234 3222	1343 3433	2332 3223	1332 2110
	17	18	19	20	21	22	23	24
Le	1101 2123	3211 1110	2101 1002	3334 4755	4553 3342	4333 4422	3112 2354	2221 1144
Do	2210 2123	4212 1120	2200 0003	3223 5856	5533 3453	4233 5422	3001 3354	2211 2254
Me	1012 3231	0011 2001	2102 3000	1347 7644	4566 6433	3256 6422	2135 5433	2322 2111
Es	1101 2133	3112 2220	2101 2113	3224 4655	3544 3353	3233 5322	2112 3354	2221 2133
RS	1111 2223	3212 1210	1101 1003	3334 5755	4534 4453	3232 4522	2012 3354	2211 1244
Ag	1001 3222	2212 2210	2001 2112	2436 5444	5544 3433	5334 4322	4123 3333	2223 2332
Wi	1111 4334	4212 2220	1101 2113	3234 5655	4534 4453	3233 5522	3112 4464	3211 3244
Ab	1101 3233	3212 2221	2111 2113	3234 5655	3533 3354	3233 5422	3122 3454	2221 2243
Ni	1100 3134	3212 1110	2100 1003	3233 5755	3524 4453	3223 4422	3112 3454	2211 2144
SF	1111 4134	2212 2111	1111 2114	3235 5655	4544 4355	4343 5432	3113 4555	1122 3132
ZS	3322 3222	2312 2121	3232 2113	2435 5534	3635 5433	3233 5424	2234 5443	2322 2211
CT	0232 2012	1112 3210	1233 3202	2224 3553	2233 4253	2223 4332	2232 4343	1033 2011
	25	26	27	28	29	30	31	
Le	2232 2333	1213 2042	2322 3212	2122 2045	4332 1343	1353 2342	5322 3442	
Do	2222 2323	1223 2053	2312 3302	3012 2145	4312 2344	2343 3452	5322 4550	
Me	1355 3321	0435 4122	1232 5311	1333 2114	5454 2332	2466 5533	3353 3432	
Es	2233 1333	1223 2042	3322 3312	2222 2144	4322 1343	2353 3343	4332 4432	
RS	2232 2433	1212 2053	2212 3302	2122 2155	4322 1344	2453 3453	4332 4441	
Ag	1354 3322	1424 2232	2222 4320	1414 2234	5533 2333	2474 3444	6342 5431	
Wi	1122 3433	1223 3153	2212 4422	2122 2156	4413 2344	2453 4453	4322 3442	
Ab	2332 1333	1323 2143	3322 4312	2123 2145	4322 1344	2453 3454	4333 4442	
Ni	2232 2423	1323 1152	2201 4312	2101 1155	4312 1354	2453 3453	4332 4442	
SF	1244 3433	1333 2231	2220 5412	2223 2244	5433 2454	2463 4355	4432 5552	
ZS	2242 4322	2434 4131	2333 4322	3333 2324	3323 3433	3464 3555	4623 5443	
CT	0022 2331	1222 3321	1233 4211	2233 2113	3213 2342	2354 2334	3433 4542	

The list of contributing observatories is given in Table 2. The following information is given for each observatory: Abbreviation for name of the observatory; geographic latitude (ϕ) and longitude (λ); geomagnetic latitude (Φ), the angle (ψ) (positive east from geomagnetic north) between the geomagnetic dipole meridian and the astronomical meridian; lower limit of the range for K-index of 9; and the average scale-value of each of the magnetic elements.

The eight indices for successive three-hour-periods of the Greenwich

TABLE 4—*Frequencies of K-indices, January to December 1940 (2928 three-hour intervals)*

lex	Observatory																		
	Le	Do	Me	Si	Es	RS	Ag	Wi	Ab	Ni	Ch	SF	Tu	SJ	Ho	ZS	Hu	CT	Wa
0	281	643	544	487	123	447	346	362	50	389	406	238	373	502	604	66	303	638	322
1	731	424	717	727	658	642	567	561	650	725	619	510	707	789	819	346	685	706	846
2	849	746	579	664	1013	745	803	782	861	787	753	719	785	860	737	955	899	776	934
3	619	583	487	510	728	607	684	680	810	565	656	753	627	512	531	984	636	551	526
4	241	279	247	263	265	310	287	365	374	301	318	446	278	177	147	377	242	162	197
5	101	119	165	137	81	104	145	115	116	97	117	188	109	52	62	146	99	65	63
6	47	51	115	67	27	35	45	37	39	40	30	52	28	27	17	38	41	20	22
7	25	38	68	41	19	23	38	18	19	17	15	18	13	6	9	13	16	7	8
8	17	27	5	15	5	3	11	5	5	3	10	3	8	2	2	3	5	2	9
9	17	18	1	17	9	12	2	3	4	4	4	1	...	1	...	...	2	1	1

TABLE 5—*Equivalent mean K-indices for the eight three-hour periods of the Greenwich day, January to December 1940*

Observatory	Equivalent mean indices for GMT interval								Equivalent mean
	00-03	03-06	06-09	09-12	12-15	15-18	18-21	21-24	
rwick	3.52	3.17	2.27	2.27	2.77	3.23	3.58	3.69	3.15
ombås	3.65	3.00	2.02	2.17	3.11	3.55	4.04	3.79	3.27
eanook	2.56	3.22	3.88	3.99	3.42	2.81	2.21	2.33	3.15
ka	2.54	3.13	3.63	4.03	3.80	3.27	2.56	2.09	3.22
kdalemuir	3.00	2.74	2.35	2.50	2.95	3.26	3.24	3.06	2.93
ıde Skov	3.02	2.74	2.32	2.35	2.84	3.26	3.41	3.30	2.98
gincourt	3.23	3.34	3.17	2.90	2.67	2.77	3.04	2.94	3.04
itteveen	2.73	2.53	2.28	2.49	2.90	3.25	3.45	3.18	2.91
ɔinger	3.04	2.74	2.45	2.53	3.03	3.38	3.41	3.27	3.04
iemegk	2.87	2.48	1.71	2.19	2.65	3.15	3.37	3.07	2.75
ıeltenham	3.19	3.21	2.87	2.67	2.44	2.60	2.81	2.90	2.87
ın Fernando	3.08	2.74	2.79	2.94	3.05	3.32	3.46	3.24	3.10
ıcson	2.62	3.01	2.99	2.90	2.42	2.59	2.41	2.48	2.68
ın Juan	2.45	2.42	2.08	2.17	2.02	2.56	2.51	2.32	2.32
ɔnolulu	2.19	2.28	2.39	2.42	2.08	2.04	2.30	2.23	2.24
-Sè	2.92	3.15	3.11	3.13	3.22	3.16	2.79	2.76	3.06
uancayo	2.24	2.21	1.82	2.04	3.22	3.94	3.20	2.18	2.73
ape Town	2.02	1.76	2.19	2.40	2.50	2.57	2.49	2.32	2.30
atheroo	2.30	2.32	2.32	2.44	2.68	2.85	2.55	2.23	2.46
Equivalent mean	2.86	2.80	2.64	2.74	2.89	3.10	3.08	2.89	2.89

Table 6—*Equivalent monthly mean K-indices, January to December, 1940*

Observatory	Month												Equi[illegible]
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Lerwick	2.77	2.52	4.84	3.54	2.72	3.17	2.60	2.47	3.04	3.03	3.03	3.56	3.[illegible]
Dombås	3.11	2.67	4.63	3.84	2.87	3.39	2.70	2.53	3.22	3.28	3.20	2.85	3.[illegible]
Meanook	2.93	2.53	4.03	3.12	3.05	3.25	3.05	2.70	3.10	3.18	3.36	3.12	3.[illegible]
Sitka	3.13	2.42	4.94	3.17	3.11	3.14	3.04	2.45	2.96	3.00	3.30	2.90	3.[illegible]
Eskdalemuir	2.76	2.44	4.50	2.94	2.63	3.08	2.51	2.48	2.56	2.56	2.62	2.53	2.[illegible]
Rude Skov	2.94	2.48	4.64	2.75	2.55	3.09	2.39	2.38	2.49	2.64	2.84	2.80	2.[illegible]
Agincourt	2.45	2.28	4.16	3.32	3.07	3.23	2.74	2.75	2.77	2.69	3.11	2.88	3.[illegible]
Witteveen	3.11	2.72	4.01	2.81	2.62	3.00	2.53	2.46	2.54	2.64	2.86	2.95	2.[illegible]
Abinger	3.03	2.76	4.18	3.01	2.83	3.07	2.70	2.70	2.85	2.85	3.02	2.85	3.[illegible]
Niemegk	2.94	2.59	3.83	2.58	2.40	3.03	2.33	2.34	2.49	2.51	2.67	2.75	2.[illegible]
Cheltenham	2.49	2.47	4.09	3.01	2.76	2.98	2.70	2.42	2.41	2.50	2.72	2.70	2.[illegible]
San Fernando	3.11	2.83	3.69	3.12	2.99	3.16	2.85	2.73	3.07	3.11	3.23	3.13	3.1
Tucson	2.61	2.40	3.73	2.69	2.51	2.71	2.41	2.18	2.58	2.51	2.71	2.59	2.[illegible]
San Juan	2.11	1.58	3.27	2.36	2.27	2.35	2.18	2.03	2.21	2.32	2.47	2.23	2.[illegible]
Honolulu	2.08	1.74	3.13	2.23	2.02	2.45	2.02	1.81	2.20	2.18	2.46	2.25	2.[illegible]
Zô-Sè	3.15	2.91	3.71	3.07	2.83	3.06	2.62	2.70	3.02	2.99	3.20	3.04	3.[illegible]
Huancayo	3.17	2.57	3.62	2.60	2.36	2.63	2.25	2.31	2.39	2.45	2.88	2.99	2.[illegible]
Cape Town	2.59	2.11	3.33	2.17	1.67	2.03	1.53	1.83	2.02	2.46	2.67	2.43	2.[illegible]
Watheroo	2.54	2.43	3.66	2.27	2.04	2.23	1.97	2.02	2.35	2.36	2.59	2.61	2.[illegible]
Equivalent mean	2.81	2.46	4.08	2.95	2.61	2.96	2.50	2.39	2.66	2.72	2.94	2.75	2.[illegible]

day as reported by each observatory for the last six months of 1940 are given in Table 3.

The frequency of occurrences of each of the *K*-indices for all 19 observatories during the year 1940 is given in Table 4. In general, the ideal of frequency distributions of *K*-indices, three or greater, has been reasonably attained. Abinger has a relatively small number of zeros and Zô-Sè somewhat higher activity than might have been expected. After two full years of indices become available, scales may be derived for reduced indices.

For the purpose of comparing daily and annual activities at the various observatories, equivalent mean indices have been computed by using the transforming key given on page 441 of the third reference.[3] The equivalent mean *K*-indices for eight three-hour periods of the Greenwich day for all observatories are given in Table 5 and those for each month in Table 6. All European observatories, and Cape Town, San Juan, Huancayo, and Watheroo, show the greatest activity around 18^{h} GMT, Agincourt, Cheltenham and Tucson around 03^{h}, and Meanook, Sitka and Honolulu around 09^{h}.

The assistance of Miss Balsam in the preparation of the tables is gratefully acknowledged.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., July 10, 1941

NEW MAGNETIC CHARACTER-NUMBERS FOR THE POLAR STATION GJÖAHAVN FOR 1904

By K. F. Wasserfall

When the report on the results of the magnetic station at Gjöahavn[1] was compiled, magnetic character-numbers were included. The system used to derive these numbers did not yield values directly comparable with the international character-numbers recently published by Van

Table 1—*Character-numbers for the Polar Station Gjöahavn for 1904*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1	1.76	0.51	0.48	2.00	0.66	0.58	1.59	1.22	0.55	0.59	0.55	0.53
2	0.57	0.60	0.55	1.36	0.60	0.38	0.50	1.90	0.59	0.48	1.11	0.39
3	0.95	0.41	0.56	1.92	0.54	0.55	0.54	2.00	0.70	0.31	0.56	0.53
4	1.71	0.66	1.13	0.59	0.60	0.51	0.90	2.00	0.40	0.43	2.00	0.57
5	0.72	0.53	0.50	0.57	0.38	0.86	0.55	0.60	0.56	0.49	1.00	0.57
6	0.46	0.60	0.52	0.52	0.42	0.90	2.00	0.61	0.58	0.58	0.53	0.37
7	0.32	0.57	0.40	1.54	0.39	0.59	1.94	0.51	0.56	2.00	0.44	0.38
8	0.33	0.58	0.42	0.53	1.27	0.35	0.61	0.58	0.55	0.62	0.42	0.20
9	0.63	0.63	0.49	0.54	0.53	0.38	1.60	0.53	0.56	0.61	0.29	0.49
10	1.09	0.59	0.31	0.56	0.38	0.54	0.54	0.54	0.44	0.43	0.21	0.24
11	0.46	0.54	0.59	1.92	0.60	0.47	0.56	0.35	1.64	0.44	0.28	0.21
12	0.56	0.54	0.60	0.60	2.00	0.60	0.47	0.44	0.61	0.57	0.16	0.27
13	0.36	0.60	0.38	0.59	2.00	0.36	0.82	0.61	0.54	2.00	0.20	0.21
14	0.17	0.56	0.22	0.39	1.80	0.61	2.00	0.55	0.53	0.53	0.25	0.61
15	0.98	1.42	0.28	0.47	0.60	2.00	0.58	0.54	0.36	0.59	0.60	0.56
16	1.52	1.37	0.21	0.30	0.58	2.00	0.60	1.70	0.56	0.48	0.94	0.38
17	0.38	0.59	0.22	0.60	0.75	0.57	0.55	1.67	0.42	0.39	0.94	0.23
18	0.28	0.58	0.41	2.00	0.60	0.59	0.58	0.54	0.60	0.40	0.60	0.24
19	0.20	0.42	0.32	1.93	0.53	0.43	0.32	0.59	0.45	0.22	0.29	0.19
20	0.50	0.17	0.48	0.32	0.60	0.54	0.59	0.55	0.50	0.34	0.23	0.31
21	0.60	0.27	0.23	0.34	0.60	0.54	0.58	1.58	0.39	2.00	0.36	0.58
22	0.51	0.46	0.36	0.54	0.55	0.44	0.59	1.04	0.57	0.61	0.38	0.25
23	0.30	0.60	0.27	0.38	0.53	0.54	0.54	0.48	0.38	0.37	0.17	0.30
24	0.48	0.42	0.44	0.61	0.58	0.53	0.30	0.46	0.66	0.46	0.31	0.21
25	0.29	0.44	0.47	0.54	0.30	0.59	0.59	0.40	1.90	0.57	0.96	0.15
26	0.21	0.34	0.92	0.57	0.54	0.73	0.94	0.27	0.60	0.39	0.54	0.59
27	0.27	0.40	0.58	0.39	2.00	1.72	0.79	0.51	0.51	0.54	0.53	0.41
28	0.91	0.47	0.43	0.42	2.00	0.61	0.59	0.41	0.38	0.55	0.29	0.31
29	0.55	0.48	0.61	0.64	1.94	0.58	0.57	0.54	0.44	0.59	0.51	0.44
30	0.68		0.48	0.61	0.60	0.54	1.72	0.64	0.61	0.67	0.53	0.23
31	0.60		0.57		0.97		0.48	0.61		0.68		0.19
Means	0.62	0.56	0.47	0.81	0.85	0.72	0.81	0.81	0.60	0.68	0.52	0.36
Int. C_1	0.69	0.55	0.42	0.62	0.61	0.50	0.57	0.46	0.53	0.58	0.54	0.55

Annual mean, Gjöahavn, 0.65
Annual mean, international, 0.55

[1] A. S. Steen, N. Russeltvedt, and K. F. Wasserfall, The scientific results of the Norwegian Arctic Expedition: A. Part II—Terrestrial Magnetism, Geofys. Pub., 7, Oslo (1933).

Dijk[2]. It seemed worthwhile, therefore, to compile new and more satisfactory numbers. Meanwhile absolute storminess tables for D, H, and V have been published[3] and these furnish means to derive better character-numbers.

Table 1 gives the daily and monthly means for these new character-numbers for Gjöahavn and the monthly means for the international character-numbers (C_I) published by Van Dijk.[2] The new numbers for Gjöahavn are derived in the same way as those for the Dombås Observatory.[4] They depend on absolute storminess for declination, AS_D. The monthly means are plotted in Figure 1. The variation from month to

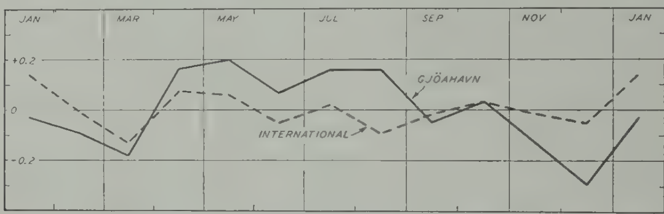


FIG. 1—ANNUAL VARIATION OF MEAN MONTHLY AVERAGES OF MAGNETIC CHARACTER-NUMBERS FOR 1904 (MONTHLY MEAN MINUS ANNUAL MEAN)

month for Gjöahavn agrees fairly well with the international numbers but the annual wave is considerably more pronounced at Gjöahavn.

Frequency of character-numbers is shown graphically in Figure 2 which indicates the frequency for character-numbers 0.0 and 0.1 to be zero whence a rapid rise of the graph to 111 for character-number 0.6.

TABLE 2—*Frequency of magnetic character-numbers at Gjöahavn for 1904*

Character-number	Number of cases	Character-number	Number of cases
0.0	0	1.0	6
0.1	0	1.1	3
0.2	25	1.2	1
0.3	32	1.3	1
0.4	58	1.4	3
0.5	71	1.5	2
0.6	111	1.6	4
0.7	8	1.7	6
0.8	3	1.8	2
0.9	7	1.9	7
		2.0	16

[2]G. van Dijk, Magnetic character of the years 1890-1905, Terr. Mag., **43**, 245-246 (1938).

[3]K. F. Wasserfall, Data for absolute storminess for the Polar Station Gjöahavn for the year 1904, Terr. Mag., **43**, 383-388 (1938).

[4]K. F. Wasserfall, On the variation of magnetic character-numbers at Dombås Observatory, Terr. Mag., **45**, 1-4 (1940).

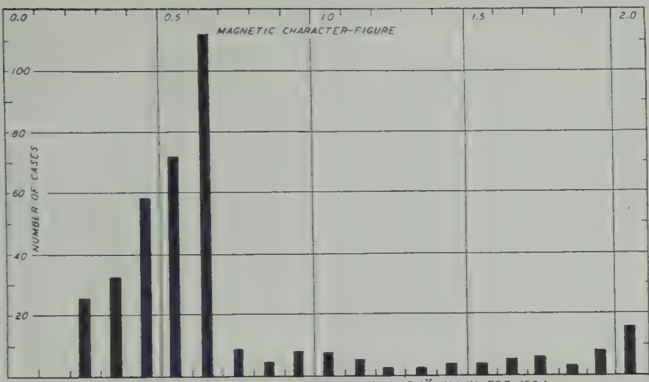


FIG. 2—FREQUENCY OF INDEX C_D FOR GJÖAHAVN FOR 1904

The graph then falls to 8 for character-number 0.7 but keeps within the limit between 1 and 7 except for number 2.00 for which there is an increase to 16 cases.

DET MAGNETISKE BYRÅ,
Bergen, Norway, March 1941

LETTERS TO EDITOR

(See also page 356)

PROVISIONAL SUNSPOT-NUMBERS FOR MAY TO JULY, 1941

(Dependent alone on observation at Zürich Observatory)

Day	May	June	July
1	44[d]	37	76
2	38[a]	21	73
3	40*	47[d]	79[aa]
4	37	53[a]	62
5	40	61[a]	47[d]
6	32[a]	70	53
7	14	61	53
8	12	*E*97[c]	47
9	28[d]	118[bd]	59[d]
10	*E*21[c]	95	62
11	23	83*	31
12	31[a]	74[a]	25
13	29	62	23
14	22	56[a]	12
15	26[d]	45	8
16	32[a]	22	23[dd]
17	38	*M*29[c]	*M*34[c]
18	23	*E*28[c]	*W*56[c]
19	*E*. .[c]?	28	49
20	28	*EM*45[cc]	*E*60[cd]
21	*E*48[ac]	40	65[d]
22	*E*45[c]	*E*36[c]	*E*62[aac]
23	58	47[d]	84
24	43[a]	61	99[dd]
25	26	59[a]	103
26	. .[a]	*E*71[ac]	113[a]
27	16	74[dd]	123[ab]
28	16	82	107
29	15	94[a]	125[d]
30	11[d]	98	128[a]
31	31[d]		133[bd]
Means	29.9	59.8	66.9
No. days....	29	30	31

Mean for quarter, April to June, 1941: 41.6 (86 days)

*Observed at Locarno.
[a]Passage of an average-sized group through the central meridian.
[b]Passage of a large group or spot through the central meridian.
[c]New formation of a group developing into a middle-sized or large center of activity: *E*, on the eastern part of the Sun's disk; *W*, on the western part; *M*, in the central-circle zone.
[d]Entrance of a large or average-sized center of activity on the east limb.

EIDGEN, STERNWARTE,
Zürich, Switzerland

W. BRUNNER

A NEW LABORATORY FOR COSMIC-TERRESTRIAL RESEARCH

By Harlan True Stetson

An initial grant from the American Philosophical Society[1] in 1935 for investigations in cosmic-terrestrial relationships together with additional funds from anonymous sources has made possible the inauguration of a program of needed observations in geophysical phenomena that has recently resulted in the establishment of a new laboratory for cosmic-terrestrial research at Needham, Massachusetts.

The site of the new Laboratory (Fig. 1) was selected after about a year of careful study of the environs of Boston from the point of view of suitability as to appropriate conditions for atmospheric-electric observa-

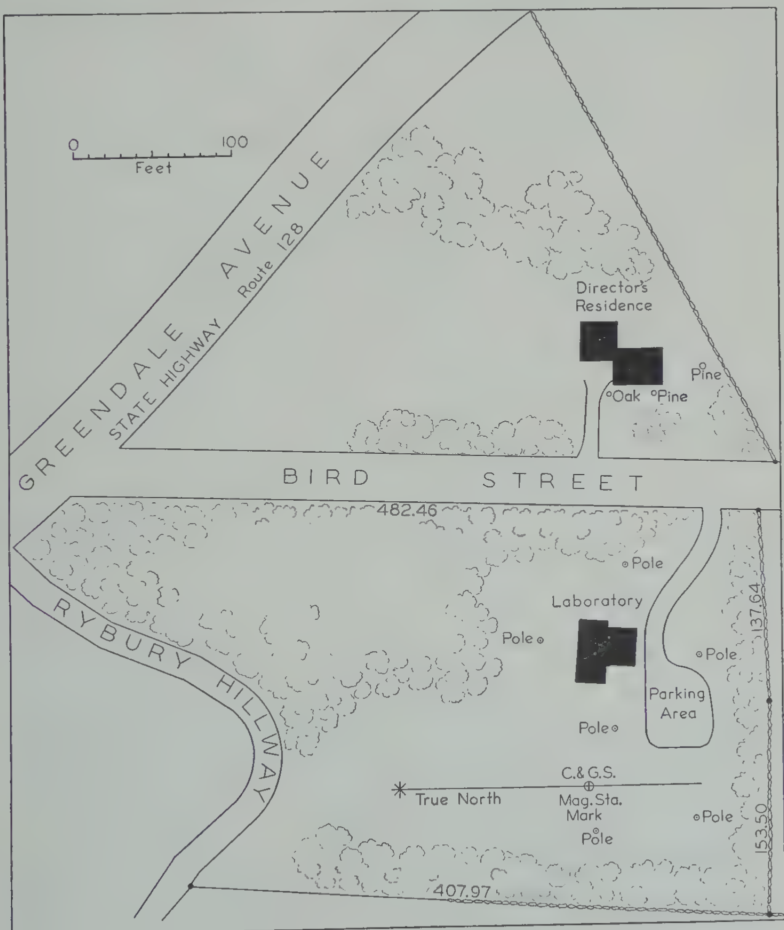


FIG 1—SITE OF THE SUBURBAN LABORATORY FOR COSMIC-TERRESTRIAL RESEARCH, NEEDHAM, MASSACHUSETTS

[1]Harlan T. Stetson, First report on the research in cosmic-terrestrial relations, miscellanea, **1**, No. 1, September, 1935; Harlan T. Stetson. Second report on the research on cosmic-terrestrial relations, Proc. Amer. Phil. Soc., **76**, No. 5, September, 1936.

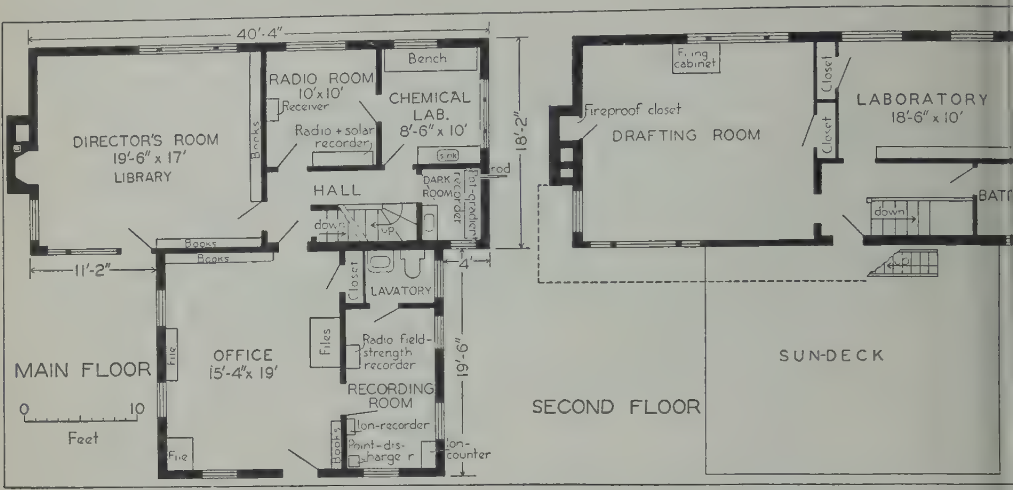


FIG 2—PLANS OF SUBURBAN LABORATORY FOR COSMIC-TERRESTRIAL RESEARCH, NEEDHAM, MASSACHUSETTS

tions, together with accessibility to the Massachusetts Institute of Technology with which the work at the Laboratory is associated.

The search for a suitable location was confined to the sector west and southwest of Boston so that the prevailing winds should insure reasonable freedom from contamination of the air incident to the congestion of a large metropolitan area. The quest resulted in the acquisition of a tract of nearly five acres in an open area within the limits of the township of Needham adjoining the State circumferential highway known as Route 128.

The land acquired, and for which the deeds were secured in 1939 and 1940, is two miles from the center of Needham in an undeveloped territory zoned for single residences. It is at a safe distance from any existing dwellings and is protected on the north of the main highway by an extensive area of the Charles River Basin held by the City of Newton as a water-reservation, and on the south by farmland. The land is unequally divided by an old town-way known as Bird Street. The property when acquired contained, on the west side of Bird Street, an abandoned masonry one-story structure approximately 20 feet by 25 feet, once used as a radio station by Press Wireless Incorporated, a syndicate of national newspapers formed in 1929 for the reception of foreign news by radio. This original building was reconstructed for use as a tentative observing station in the program of cosmic-terrestrial relationships and first occupied in April, 1939.

After a year of such use and since the location appeared admirable for the purpose, plans were completed for a more substantial building to make possible the further development of research in the field. The new building, as completed in October, 1940, comprises a two-story structure adding to and incorporating the original building (Fig. 2). The layout is approximately *L*-shaped and affords 2,500 square feet of available floor space, including a basement and not including a sun-deck and observing roof. The architecture is functional modern.

The main entrance facing south leads directly into a room 16 feet by

18 feet, utilized as a secretary's office with facilities for filing and computing. The adjoining room, 8 feet by 14 feet, serves as an instrument- and record-room. Here is maintained an automatic recorder for measuring the radio field-intensities of distant broadcasting stations, a pliotron ion-counter and point-discharge recorder, all automatic in their operation.

A door in the north side of the main office opens into a short corridor from which entrances lead to the director's office and library, an assistant's office and instrument-room, a chemical laboratory, and a photographic dark room. On the second floor are a chart and drafting room and an additional laboratory. A south door from the second-floor landing leads to the sun-deck from which a gangway proceeds to the roof of the main building where instruments have been installed for the measurement of solar radiation at specified spectral regions and for the determination of ultraviolet light. A basement, 18 feet by 40 feet, accommodates an instrument-shop and a fuel-oil heating plant that provides winter air-conditioning throughout.

The building is of masonry construction, stuccoed on the outside. In the original structure hollow terra-cotta tile was used, and cinder-block in the new section of the building. The interior, with the exception of the director's office and library, is sheathed with masonite and floored with marbleized linoleum. There is a fireplace on the north side of the director's office and library; the floor is of dark oak and the walls of walnut weldboard. The hollow building blocks and the cellotex ceilings used throughout afford excellent insulation properties. The grounds have been landscaped appropriate to the natural surroundings of the Laboratory (Fig. 3).

A director's residence of modern functional design in keeping with the architecture of the Laboratory was completed and occupied in the early part of 1941. The house with attached two-car garage is situated on the east side of Bird Street at a distance of approximately 120 feet from the Laboratory.

The primary function of the Laboratory is the geophysical investigation of such relationships as may exist between cosmic phenomena exterior to the Earth and such terrestrial phenomena as may result from or vary with changes in the Earth's exterior environment.

FIG. 3—SUBURBAN LABORATORY FOR COSMIC-TERRESTRIAL RESEARCH, NEEDHAM, MASSACHUSETTS (DIRECTOR'S RESIDENCE IN BACKGROUND AT RIGHT)

A large part of the observational work at present being carried on concerns itself with problems of atmospheric electricity. Continuous measurements are being made of the field-strengths of radio waves propagated from distant stations which have already shown not only diurnal and seasonal variations but variations accompanying the 11-year solar cycle. An RCA communication-receiver is connected through the AV-tube to a Leeds and Northrup recording galvanometer and the entire circuit is standardized periodically with a General Radio standard-signal generator. Broadcasting stations whose carrier-waves are under observation have cooperated most heartily in supplying detailed copies of transmitter-logs giving the conditions at the sending end for day-by-day comparison with the field-strengths as measured at the Laboratory.

Because of the probable importance of the radiation of the Sun in affecting not only the ionization of the reflecting layers of the upper atmosphere but also conditions at the Earth's surface, a solar recorder has been installed on the roof of the Laboratory. This communicates with a Leeds and Northrup micromax located in the instrument-room. At present the intensity of solar radiation transmitted through the atmosphere upon a horizontal surface is being recorded in six different regions of the spectrum through a series of specially selected Corning-glass filters. The filters are changed electrically at ten-minute intervals. The apparatus is automatically set into operation at sunrise and remains in continuous operation until sunset. Provisions have been made for standardizing at frequent intervals the photronic cell utilized in the apparatus. At sunset the circuit is automatically switched so that night radio field-strengths are recorded, thereby utilizing the micromax-recorder in a double-duty role.

The integrated intensity of ultraviolet transmitted through the Earth's atmosphere in the region of 3400 to 4000 Ångströms is measured through certain fixed hours each day by means of special glass rods sensitive to ultraviolet light. The development of these rods and their use in the measurement of ultraviolet has been due to the painstaking work of Dr. H. Landsberg[2] of Pennsylvania State College, and a member of the Special Committee on Cosmic-Terrestrial Relationships of the American Geophysical Union. These rods of one mm in diameter and five cm in length contain approximately one half of one per cent each of cerium oxide and vanadium oxide with the result that the clear unexposed rods attain certain hues becoming definitely violet upon continued exposure to ultraviolet light. The tint of the rods after one day's exposure is compared with that of a series of standardized rods of the same composition that have been exposed to known quantities of ultraviolet in the Laboratory. A special instrument for rapid and efficient comparison has been designed and constructed for this purpose. To insure the exact exposure each day a mechanical device has been made in the workshop of the Laboratory that will automatically expose one of these rods between the hours of 9 and 5, eastern standard time, or for any other interval that may be selected. Thus a registration of the integrated ultraviolet in the region to which the rods are photosensitive is obtained on a standardized basis each day and affords a record of the

[2]Helmut Landsberg, A method of measuring radiation of short wave length by means of a photochemical reaction in a special glass, Penn. State College Studies, No. 5, July, 1940; also H. Landsberg and W. Weyl, Measurements of ultra-violet radiation sums with photosensitive glass, Bull. Amer. Met. Soc., **20**, pp. 254-256, 1939.

ultraviolet of Sun and sky under all sorts of conditions. Indirectly, additional information is obtained concerning the transparency of the lower atmosphere to this region of the spectrum, provided the ultraviolet radiation from the Sun at higher altitudes is otherwise obtained.

Apparatus for determining the potential-gradient by means of measuring the charge collected on a horizontal rod has been installed and is at present in manual operation. The ionium-collector for insuring equality of potential for the rod and the atmosphere has been loaned by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, to which acknowledgment is due. It is proposed that this apparatus shall be ultimately made self-recording so that the potential-gradient may yield an unbroken hourly record throughout each day. Experiments are likewise being conducted with a modified form of the Ebert ion-counter rendered automatically recording by the substitution of a General Electric FP-54 vacuum-tube for the usual electrometer. The grid of the tube is connected to the coaxial rod of the collection-cylinder which is at present charged negatively, thereby forcing the small negative ions to the central rod. The accumulation of the negative ions changes the charge on the grid. The plate-current of the tube which varies with the charge on the grid is measured on a Brown recording potentiometer adapted for the purpose. The operation of the aspirator that draws outside air into the apparatus together with the other necessary electrical circuits is controlled by a timing mechanism operating the appropriate switches automatically.

A point-discharge apparatus (Fig. 4) records the passage of any electrical discharge from the sky to the Earth or the Earth to the sky between the ranges of -5 to $+5$ microamperes. The ordinary fair-weather current is sufficiently small not to disturb sensibly the zero of

FIG. 4—CORNER OF A RECORDER-ROOM, SUBURBAN LABORATORY FOR COSMIC-TERRESTRIAL RESEARCH, NEEDHAM, MASSACHUSETTS

the recording galvanometer, but at irregular intervals discharges may occur for a period of from one to two hours' duration, usually first from the sky to the Earth, to be followed by a discharge in the reversed direction. It has been found that discharges invariably accompany sharp showers and in general snowfall. Long rain-storms, however, are seldom accompanied by any appreciable deflections of the point-discharge apparatus. Near-by thunder-storms of course are invariably accompanied by discharges exceeding the range of the instrument. Whether or not electrical conditions of the lower atmosphere favorable to sky-to-Earth or Earth-to-sky discharges show any correspondence to ionospheric changes that are reflected in the radio field-strengths is a question for which information may be gathered through the continuous operation of these instruments.

Provisions have been made on the program for certain geomagnetic observations and through the cooperation of the United States Coast and Geodetic Survey, a suitably marked station was located in October, 1940, on the grounds of the Laboratory. Preliminary results that may be subject to certain corrections give at present for the position of the plate, latitude 42° 17′.6 and longitude 71° 12′.0, and for the mean declination of the compass at this locality on that date (October 28, 1940) 15°.3 west.

Among the problems under investigation are the diurnal, annual, and other periodic fluctuations in field-strengths of radio-wave propagation, the study of the distribution of ions at the Earth's surface, the study of the atmospheric potential-gradient and atmospheric-electrical discharges, solar effects on the transmission of time-signals propagated by radio, and variations in the quantity and quality of transmitted sunlight. Provisions have also been made for investigations of radiation and electrical-potential effects on the germination and growth of plants since biological phenomena must inevitably respond to environmental changes. Whether or not such environmental changes may be found to be cyclical and ultimately predictable depends upon the accumulation of such data as mentioned above.

It is already gratifying that much of the early pioneering work in th- investigation of radio-wave propagation with respect to cosmic phee nomena has, in a little over a decade, made it possible for radio engineers to anticipate the range of usable frequencies for communications based upon the major changes in the sunspot-cycle. Similarly, it would appear probable that further investigations will ultimately yield important contributions to the meteorology of the upper air. The significance of the close correspondence between atmospheric and geomagnetic phenomena to changes taking place exterior to the Earth emphasizes the growing importance of the field of cosmic-terrestrial relationships. Observational data gathered by recording instruments continuously maintained at this Laboratory must yield results of increasing value with the persistence of the records.

It should be emphasized that the primary purpose of the establishment of the Laboratory is the observation and the accumulation of geophysical data pertaining to the action, reaction, and inter-action of cosmic and geophenomena.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
SUBURBAN LABORATORY,
Needham, Massachusetts, June, 1941

ATMOSPHERIC-ELECTRIC RESULTS FROM WATHEROO, WESTERN AUSTRALIA, FOR THE PERIOD 1924-1934

By G. R. Wait and O. W. Torreson

Abstract—Measurements with continuously recording instruments of the potential-gradient and positive and negative conductivities of the air, have been made since 1924 at the Watheroo Magnetic Observatory, Western Australia. Atmospheric-electric data for the 11-year period, 1924-34, have been summarized and curves drawn showing the behavior of the recorded elements and the calculated air-earth current through the day and year. The pronounced effect of smoke on the various elements from burning bush is illustrated and discussed. The calculated ratio of the columnar resistance of the air over Watheroo to that over the ocean shows a diurnal variation which has essentially the same character for all seasons of the year and also appears to be similar in character to that for Huancayo, Peru, and for Tucson, Arizona, when each is plotted on its own local time. The summer, but not the winter potential-gradient diurnal variation, is in good accord with that found over the ocean. Examination of the factors controlling this element has led to an understanding of the cause for the lack of agreement in the case of the winter curves.

Since January, 1924, measurements have been obtained with continuously operated recording instruments of the potential-gradient and positive and negative conductivities of the atmosphere at the Watheroo Magnetic Observatory of the Department of Terrestrial Magnetism, Carnegie Institution of Washington. The present paper presents and discusses results of these measurements through the year 1934.

The Watheroo Magnetic Observatory occupies a site approximately one-half mile square on an almost flat sand-plain in Western Australia, 55 miles inland from the Indian Ocean. The Station is at an altitude of 244 meters, in latitude 30° 19′ south, and longitude 115° 52′ east of Greenwich. There are eight major buildings and several lesser ones on the site; none of these is over 20 feet high. The Atmospheric-Electric Observatory is 350 feet from the nearest of the other buildings. A few trees have been planted or permitted to grow on the site; the nearest of these are 15 to 20 feet high and some 200 feet distant from the Atmospheric-Electric Observatory. All of the trees at the Station are less than 30 feet high.

The surrounding region is sparsely inhabited, the nearest habitation being two miles to the eastward and the next nearest about seven miles to the northeast. The village of Watheroo, ten miles to the east, is a community of only a few families. The nearest town is 40 miles to the southeast and the nearest city, Perth, the capital of Western Australia, is 120 miles to the south.

Snow never falls at Watheroo and the rainfall, which averaged 17.3 inches per year in the 11 years under discussion, varies so as to divide the year into a wet season (May to October) and a dry season (November to April), as shown in Table 1. In the four rainiest months, May to August, more than 60 per cent of the rainfall occurs, averaging between two and three inches per month. In the five driest months, November to March, the average monthly rainfall is between two-tenths and three-tenths of an inch per month.

In this relatively dry climate the vegetation is sparse, consisting chiefly of bush-growth up to five or six feet high, and scattered small trees. Farms lie to the north, east, and southeast, but to the west, between the Observatory and the ocean, the land is undeveloped.

In the dry season fires in the "bush" are frequent and much smoke comes to the Observatory from this source, generally arriving in the

middle or late afternoon and then being dissipated the following morning. The very conspicuous effect of the smoke on the atmospheric-electric elements will be discussed in a later part of the paper.

The Atmospheric-Electric Observatory is a flat-roofed concrete building three meters high with double walls, floor, and ceiling. The walls are protected from the Sun's rays by a wooden louvred enclosure, while the floor is raised above ground-level so that air may circulate beneath it. The diurnal variation in temperature within the building is small and investigation has shown that the resulting temperature-effects on the instruments may be neglected.

For potential-gradient measurements an ionium-coated disc is used as the "collector" mounted on an amber-insulated rod projecting 1.00

Table 1—*Total monthly rainfall (inches) and days on which rain fell, Watheroo Magnetic Observatory, 1924-1934*

Month	Year											
	1924		1925		1926		1927		1928		1929	
	Days	Inches	Days	Inches	Days	Inches	Days	Inches	Days	Inches	Days	Inches
Jan.	3	0.02	6	0.72	4	0.06	3	0.03	8	0.67	1	0.5[illegible]
Feb.	3	0.14	7	0.69	5	0.16	3	0.24	1	0.00	6	2.5[illegible]
Mar.	4	0.06	5	0.14	8	0.50	13	3.74	5	0.16	5	0.4[illegible]
Apr.	2	0.05	7	0.14	18	2.18	5	0.35	6	0.57	3	0.0[illegible]
May	15	2.17	17	1.89	15	2.04	9	1.26	9	1.45	18	3.5[illegible]
June	15	2.38	14	3.06	15	2.81	11	3.89	11	1.29	15	5.1[illegible]
July	13	2.04	14	2.66	23	4.85	16	2.53	19	3.97	17	2.6[illegible]
Aug.	13	3.05	7	0.42	19	2.52	19	1.26	17	1.76	13	1.9[illegible]
Sep.	13	1.03	10	2.01	10	1.44	13	1.26	14	1.38	8	0.5[illegible]
Oct.	16	2.00	18	0.49	11	1.49	10	0.61	7	0.69	11	0.5[illegible]
Nov.	11	0.46	10	0.24	10	1.63	2	0.06	2	0.06	7	0.6[illegible]
Dec.	1	0.05	8	2.00	3	0.01	6	0.23	7	2.40	4	0.0[illegible]
Totals	109	13.45	123	14.46	141	19.69	110	15.46	106	14.40	108	18.5[illegible]

Month	Year											
	1930		1931		1932		1933		1934		Total	
	Days	Inches	Days	Inches	Days	Inches	Days	Inches	Days	Inches	Days	Inches
Jan.	0	0.00	1	0.00	7	0.36	3	0.06	8	2.03	44	4.49
Feb.	1	0.00	1	0.03	1	0.00	2	0.15	2	0.11	32	4.11
Mar.	8	0.75	3	0.09	5	4.05	7	0.17	11	6.48	74	16.5[illegible]
Apr.	11	1.07	8	0.57	10	1.42	3	0.36	8	3.37	81	10.10
May	11	0.56	11	4.49	13	2.31	14	3.11	9	0.94	141	23.79
June	20	6.62	10	1.93	12	1.79	14	5.99	14	2.44	151	37.36
July	18	3.62	21	4.20	18	3.05	12	1.73	13	2.84	184	34.10
Aug.	23	1.75	17	3.44	18	5.56	11	1.91	13	1.87	170	25.4[illegible]
Sep.	14	0.93	17	2.04	8	0.73	8	1.32	16	0.95	131	13.62
Oct.	11	1.42	9	0.49	12	1.99	11	1.25	7	0.17	123	11.17
Nov.	8	0.21	1	0.12	1	0.01	5	0.09	5	0.14	62	3.67
Dec.	3	0.09	7	0.67	3	0.08	1	0.23	5	0.10	48	5.89
Totals	128	17.02	106	18.07	108	21.35	91	16.37	111	21.44	1241	190.29

meter from the louvred wall of the atmospheric-electric building at a height of 2.45 meters above ground-level. The collector-rod is connected to the needle of a Dolezalek quadrant-electrometer which had, during the 11 years 1924-34, a sensitivity of approximately four volts per mm of deflection on a photographic sheet mounted on a rotating drum one meter from the electrometer. Weekly calibrations were made in the 11 years for the control of electrometer-sensitivity, as were also monthly determinations of the factor required to reduce recorded potentials to values of potential-gradient in volts per meter. This factor was 1.31 from January, 1924, to March, 1925. In April, 1925, a radio mast and antenna were removed from the vicinity of the atmospheric-electric laboratory and the factor was thereby reduced to 1.16. It thereafter decreased slowly and in 1934 was 1.10.

The instruments for recording the conductivity of the air consist of two similar units of modified Gerdien apparatus [see 1 of "References" at end of paper]. The earthed air-flow tubes, 16 cm in diameter, are installed vertically between floor and roof of the building, the air being drawn in from above the roof and exhausted between the floor and the ground. A short cylinder, or rod, coaxial within each tube, is connected to one pair of quadrants of a Dolezalek electrometer, the other pair of quadrants being connected to the case of the electrometer which is insulated and maintained at a constant potential of approximately 20 volts above ground. The two pairs of quadrants are permanently connected through a high-resistance ionium-cell (10^{11} ohms) of the type developed by Swann and Mauchly [2]. Under these conditions, when air is drawn through the air-flow tubes at a suitable rate, the electrometer shows a steady deflection determined by the atmospheric conductivity, the potential on the central rod, the electrometer-sensitivity, and the resistance of the radioactive cell. The deflection is photographically recorded on a rotating drum. Once each hour a zero is secured through the application of a potential to a cylindrical condenser, consisting of several concentric cylinders, mounted in each air-flow tube. The condenser removes all the high-mobility ions as they are brought in with the air from the outside.

Calibrations of the conductivity-instruments were made weekly in the years 1924-34, the currents representative of a range of values of conductivity being produced with the aid of a rotary slide-wire potentiometer [3], giving uniform variation in potential-difference, used in conjunction with a small fixed cylindrical air-condenser. Scale-values for both conductivity-instruments were maintained throughout the 11-year period at between 10×10^{-6} and 15×10^{-6} esu per mm of deflection on the photographic record located about one meter distant from the electrometers.

Notes regarding the weather were made daily, describing the kind and quantity of cloud at frequent intervals through the daylight hours, and record was kept of the occurrence of fog, mist, haze, dew, and frost, and of the smoke in the air. Periods of rainfall were carefully noted and described as gentle or heavy showers, continuous rains, thunder-showers and thunder-storms, and the amount of rainfall was measured with a standard United States Weather Bureau rain-gage. A barograph, thermograph, and hygrograph, were installed in a standard shelter and kept in continuous operation. Wind-force and wind-direction were recorded

from January, 1925, with a Dyne's pressure-tube anemograph at a height of 40 feet above ground-level.

Having records of the several meteorological elements and the accompanying daily notes on weather, it has been possible to classify each of the days in the 11-year period meteorologically, according to fair weather and bad weather, and to select from the fair-weather days the quiet, least-disturbed days.

In the years 1924 to 1934, comprising a period of 4018 days, simultaneous records in all three atmospheric-electric elements—potential-gradient, positive conductivity, and negative conductivity—were obtained on 2341 days, an average of 18 days per month. Of the remaining days some were lost through failure or maladjustment of one or another of the three instruments but most were lost through bad weather. With thunder-clouds nearby, or during thunder-storms, the potential-gradient became so great, or varied so much from positive to negative, as to be unrecordable with the sensitive apparatus used for that element.

From the complete days, nearly a thousand days were discarded after careful study of the records themselves and of the conditions of weather, in order to obtain least-disturbed, fair-weather days for the study of the electrical conditions prevailing in fair weather. Smoke in the air accounted for most of the days discarded, although dust-storms during high winds, and mild bad-weather disturbances, caused some discarding of days.

Smoky days were found chiefly in the driest months of December to March, but in November and April also a few smoky days were usually found. In the final selection of least-disturbed days from December to March there are only five to seven days per month, on the average, while in the remaining months there are 12 or 13 days.

Values of air-earth current have been computed from potential-gradient and conductivity using the formula $i = G(\lambda_+ + \lambda_-)/30{,}000$ where i is the air-earth current in 10^{-7} esu, G is the potential-gradient in volts per meter, and λ_+ and λ_- are the conductivities in 10^{-6} esu. Owing to the excessive amount of computation that would be required to obtain air-earth currents for every hour of the 1381 selected days, this was not undertaken; instead approximate air-earth current values were computed using the 11-year means of potential-gradient and conductivity for each hour of the day in each month. Later, for four representative months, January, March, June, and July, computations were made of air-earth currents for single-year means for each hour of the day and the resulting values, when averaged for the 11-year period, were consistently two or three per cent lower than those directly obtained for 11-year means. The character of the diurnal-variation curve for air-earth current was, therefore, essentially the same for both methods of treatment.

Diurnal variation—In Figures 1 to 4 are shown the average diurnal-variation curves in each month, for the 11-year period, for potential-gradient, positive and negative conductivity, and computed air-earth current. The scales for the Figures have been kept the same and seasonal changes and other interesting features may accordingly be readily seen.

In the early months of the year the conductivities are in general low and the potential-gradient is high, but as the year progresses into the wet season (May to October) the conductivity-values increase and the poten-

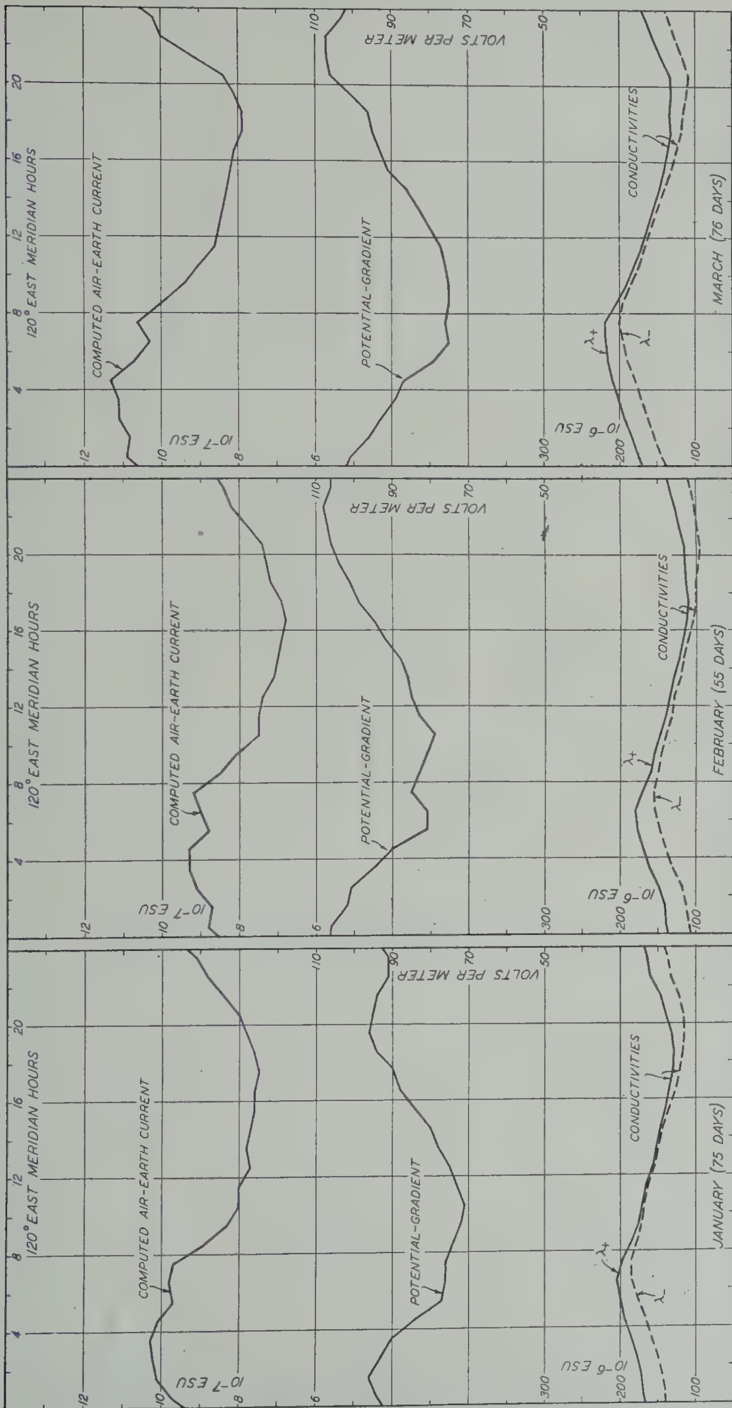


FIG. 1—DIURNAL VARIATION IN RECORDED POTENTIAL-GRADIENT AND CONDUCTIVITIES AND IN COMPUTED AIR-EARTH CURRENT FOR SELECTED FAIR-WEATHER DAYS, 10-YEAR MEANS FOR JANUARY AND FEBRUARY, 1925-34; 11-YEAR MEANS FOR MARCH, 1924-34, WATHEROO MAGNETIC OBSERVATORY

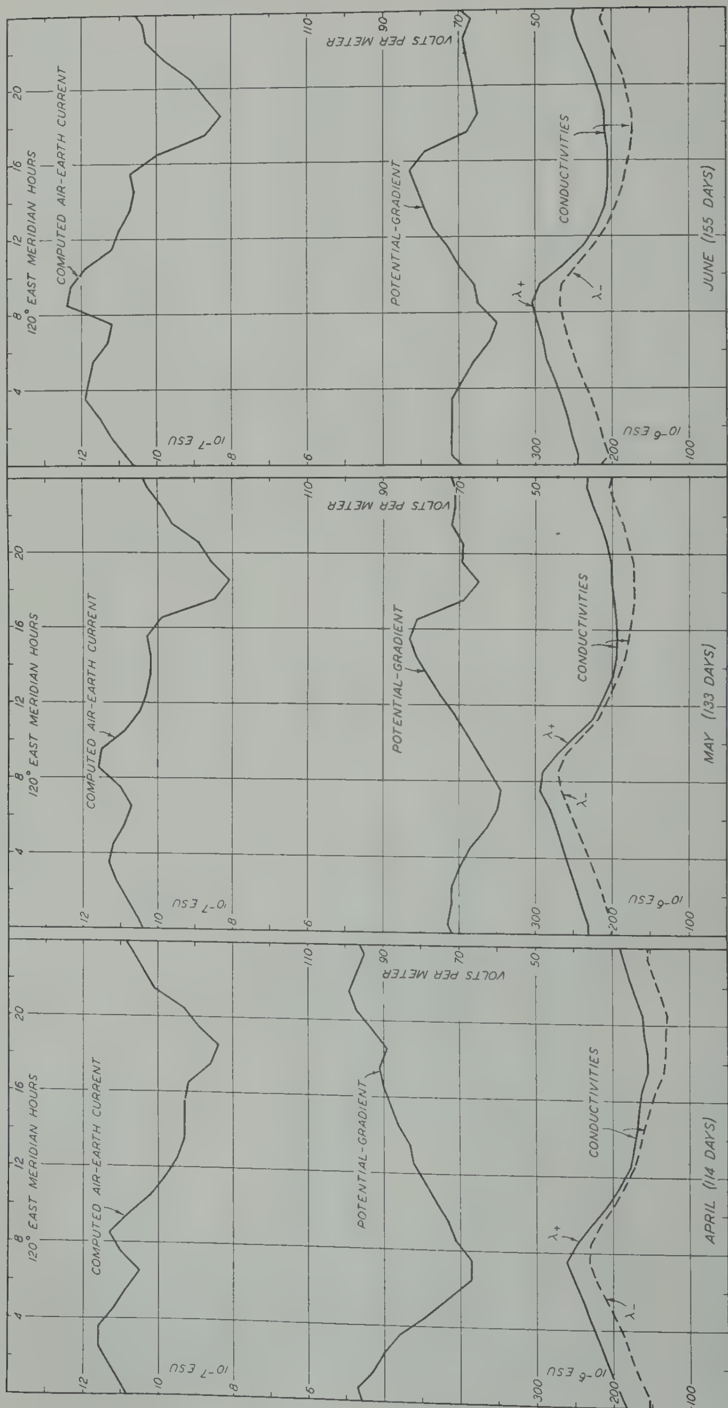


FIG. 2—DIURNAL VARIATION IN RECORDED POTENTIAL-GRADIENT AND CONDUCTIVITIES AND IN COMPUTED AIR-EARTH CURRENT FOR SELECTED FAIR-WEATHER DAYS, 11-YEAR MEANS FOR APRIL, MAY, AND JUNE, 1924-34, WATHEROO MAGNETIC OBSERVATORY

FIG. 3—DIURNAL VARIATION IN RECORDED POTENTIAL-GRADIENT AND CONDUCTIVITIES AND IN COMPUTED AIR-EARTH CURRENT FOR SELECTED FAIR-WEATHER DAYS, 11-YEAR MEANS FOR JULY, AUGUST, AND SEPTEMBER, 1924-34, WATHEROO MAGNETIC OBSERVATORY

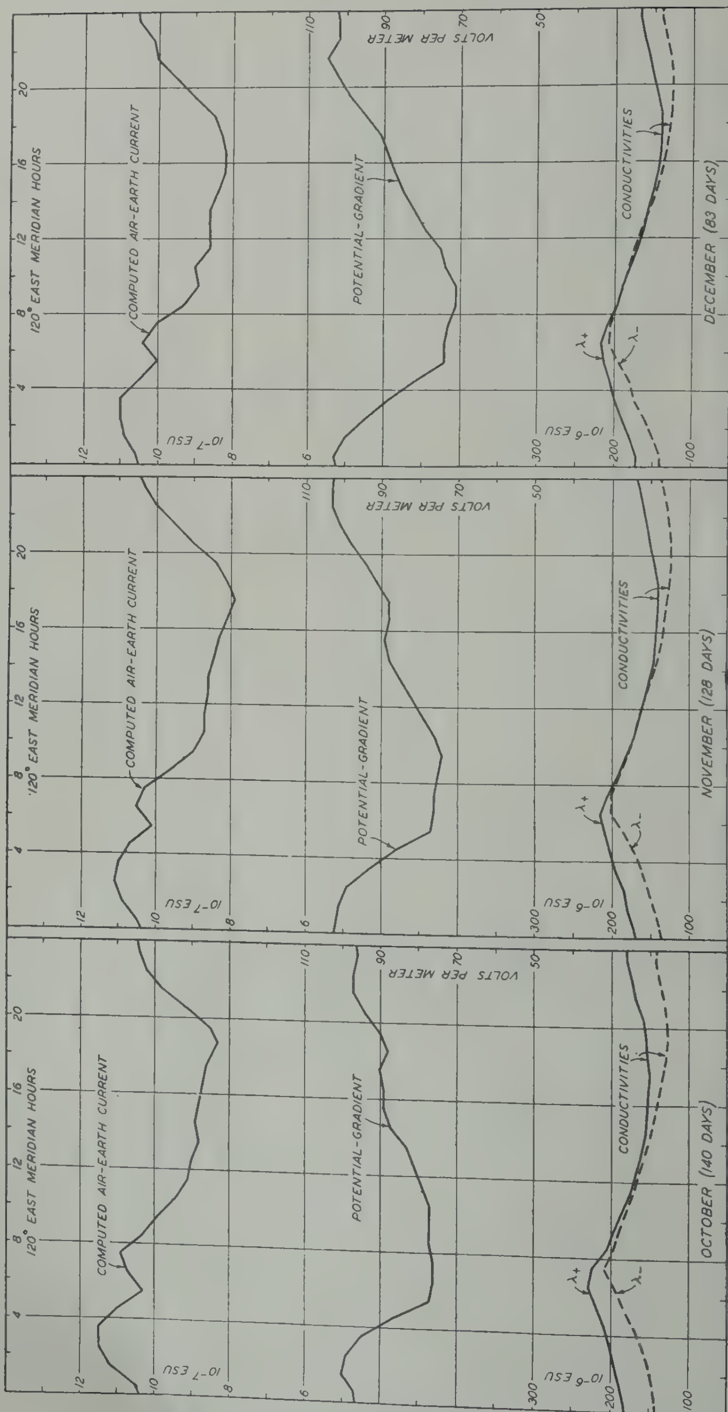


FIG. 4—DIURNAL VARIATION IN RECORDED POTENTIAL-GRADIENT AND CONDUCTIVITIES AND IN COMPUTED AIR-EARTH CURRENT FOR SELECTED FAIR-WEATHER DAYS, 11-YEAR MEANS FOR OCTOBER, NOVEMBER, AND DECEMBER, 1924-34, WATHEROO MAGNETIC OBSERVATORY

tial-gradient decreases. In the late months of the year there is a return to low conductivities and high gradients. In view of these reciprocal changes, a smaller seasonal effect on computed air-earth current would be anticipated and this was found to be the case. However, in January and February, the smokiest months of each year, the air-earth currents were much lower than in all the other months, and this is perhaps due to increased resistance of the air-column over the Station because of the accumulation of smoke at considerable heights in the atmosphere.

Seasonal differences in diurnal variation—The diurnal variation in potential-gradient is strikingly different in the wet and dry seasons of the year. In the dry summer season the variation is regular in character and the maximum value of potential-gradient occurs near midnight, 120° east meridian time (EMT). In the wet, cold season the diurnal-variation curve is broken and irregular with a maximum between 14^h and 17^h. The conductivity-curves show less seasonal difference. They are regular throughout the year, but the times of maximum and minimum change somewhat with season, occurring at about 06^h and 18^h, respectively, during the hot season and at about 08^h and 16^h during the cold season.

It should also be noted that the two conductivities are not in phase; both maximum and minimum occur at a later time for the negative than for the positive. However, both maximum and minimum of the negative conductivity do not lag to the same extent. While the maximum lags about an hour, the minimum lags two hours or more, so that the interval between maximum and minimum is smaller for positive conductivity than for negative. This difference in character of diurnal variation of the two conductivities gives rise to a diurnal variation in the ratio of positive to negative. The variation in this ratio through the day, for different times of year, will be discussed in detail later when consideration is given to the application of the "electrode-theory" of J. Scholz [4] to the data here presented.

The diurnal-variation curves for computed air-earth current reflect the seasonal differences in the potential-gradient curves, being more irregular in the wet season than in the dry, without, however, departing from the essential characteristics of an early-morning maximum and an early-evening minimum.

The seasonal difference in each element is more easily seen by comparing the curves in Figure 5. Mean curves are given for the period November to March, representative of the hot, dry season of the year, and for the period May to August, representative of the cold, wet season. All elements differ considerably in both magnitude and character of variation for the two seasons but the potential-gradient is outstanding in this respect. For a few hours around noon both magnitude and variation in potential-gradient are similar in the two seasons. For all other hours of the day the difference is very marked. The noted similarity during the few hours around noon is unexpected, for both conductivities are much higher at all hours of the day during the wet than during the dry season and one might accordingly expect the potential-gradient to be lower at all hours during the wet than during the dry season. In view of the above consideration, it is apparent that the air-earth current is particularly high around noon during the wet as compared with the dry season, as may be seen from the upper set of curves in Figure 5. The factor, as

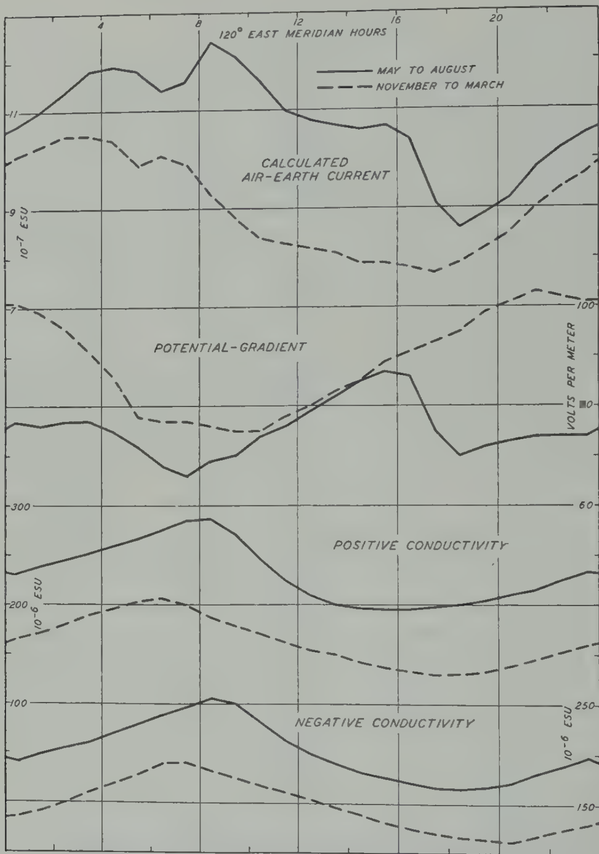


FIG. 5—SEASONAL DIFFERENCES IN ATMOSPHERIC-ELECTRIC ELEMENTS, SELECTED FAIR-WEATHER DAYS, WATHEROO MAGNETIC OBSERVATORY, 1924-34 (MAY TO AUGUST, COLD WET SEASON, 580 DAYS; NOVEMBER TO MARCH, HOT DRY SEASON, 407 DAYS)

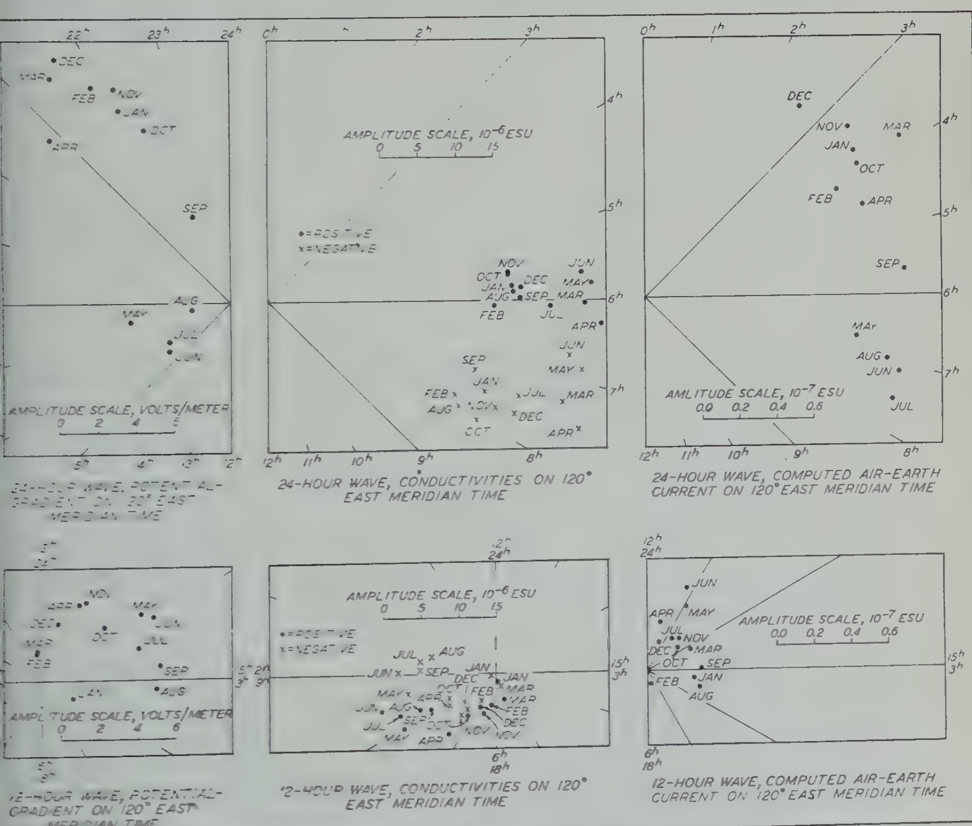
will be apparent from later discussions, most responsible for this difference in character of the air-earth current curves is the total potential between Earth and the upper conducting layer.

Harmonic analysis—Some of the features of the diurnal-variation curves for the different elements are further revealed by harmonic analyses, the results of which are given in Figure 6. In the top row of the Figure are three harmonic dials for the 24-hour waves in potential-gradient, conductivity, and computed air-earth current. In the bottom row are the corresponding dials for the 12-hour waves. For all three elements, the amplitude of the 12-hour wave is, in general, only one-fourth or one-fifth as large as that of the 24-hour wave. Exceptions to this generalization are found in the potential-gradient for the months from May to September, where the 12-hour wave exceeds the 24-hour wave in amplitude, being between 1.2 and 2.9 times as great.

The phase-angles for the 24-hour waves in potential-gradient fall into two groups. In one group are the eight months from September to April, with their maxima between 21^h and 23^h, 120° EMT, or 13^h and 15^h GMT.

These are in good agreement with the time of maximum of the universal 24-hour wave over the oceans found by Mauchly [5]. The four remaining months of May to August have their maxima between 15^h and 18^h, 120° EMT, or between 07^h and 10^h GMT, and thus are in disagreement with the universal 24-hour wave.

This disagreement, which was noted in the earliest years of recording, led to careful investigation and testing over a period of months of the potential-gradient apparatus. It was thought that with frequent fogs, mists, and rains from May to August, there might be insulation-leak during the night hours when the humidity is high, in spite of all efforts to prevent it. Leaks at such times would obliterate the normal maxima and might be expected to give diurnal-variation curves similar to those obtained. It was finally concluded from the tests that insulation-leak was not high and therefore could not be responsible for the unusual features of the diurnal variation of potential-gradient in the wet season. The present study of the 11 years of record supports this conclusion. It appears now that other elements—conductivity, air-earth current, and the total resistance of the air-column over the Station—undergo diurnal



6—HARMONIC ANALYSIS OF MONTHLY MEAN CURVES OF POTENTIAL-GRADIENT, CONDUCTIVITY, AND COMPUTED AIR-EARTH CURRENT FOR -YEAR PERIOD, 1924-34, WATHEROO MAGNETIC OBSERVATORY

changes which can account for the unusual variation of potential-gradient in the wet season. This will be discussed in some detail later.

Returning to Figure 6, the 24-hour wave in positive conductivity has a maximum at 06^h, 120° EMT, while in the negative conductivity the maximum occurs more than an hour later. This lag of about one hour is a persistent feature in all months throughout the 11 years. It is also readily seen in the 11-year means of the conductivities in Figures 1 to 4, as was pointed out earlier. The 12-hour waves for the two conductivities, in Figure 6, also show a phase-difference though it is not equally pronounced in all months. The seasonal changes in conductivity, seen in Figures 1 to 4, involving changes in the time-interval between maximum and minimum with change in length of day, are not brought out by the harmonic analysis.

The 24-hour wave for computed air-earth current in Figure 6 shows a considerable systematical annual change in phase. In the dry season of November to March, the maximum occurs at 03^h or 04^h, 120° EMT, and in the wet season of May to August, it occurs at 07^h or 08^h, 120° EMT. This large shift in the time of maximum appears from evidence to be presented later, to be governed chiefly by the behavior of the total potential between ground and upper conducting layer, since, as the later discussion will show, the total resistance between ground and conducting layer preserves the same type of diurnal variation throughout the year.

The 12-hour wave in air-earth current, as indicated by Figure 6, shows no systematic annual change in time of maximum. The amplitude of the 12-hour wave is not as large as that of the 24-hour wave, being only about one-third as great in May and June and about one-fifth as great during the remaining months. In summarizing the more important features shown by the harmonic dials in Figure 6, there are four points of particular interest: (*a*) For all three elements, the amplitude of the 12-hour harmonic is generally small compared with that of the first harmonic; (*b*) the phase-angle of the 24-hour wave of the potential-gradient in each of the months from May to August differs radically from the phase-angle of the well-known universal wave found in the curves over the oceans, while for each of the remaining months there is good agreement with the universal wave; (*c*) the phase-angle of the 24-hour harmonic for both positive and negative conductivities remains essentially constant throughout the year, although the time of maximum of the negative conductivity occurs later than that of the positive by about one hour; and (*d*) the 24-hour harmonic in computed air-earth current has essentially a constant amplitude throughout the year, while the phase-angle changes in a regular manner, giving a much earlier time of maximum in December and January than in June and July.

Annual changes—The annual changes in conductivity, potential-gradient, and calculated air-earth current are shown in Figure 7 for each of the 11 years. Both positive and negative conductivities are highest during the wet months of May to August, with the June values most frequently the highest of all. February is most frequently the month of lowest conductivity, although during the other smoky months the values are also low in all years. In all months, negative conductivity values are lower than positive. The annual change in potential-gradient is opposite to that in conductivity, the smoky months of November to March having the highest values and the wet months of May to August having the lowest.

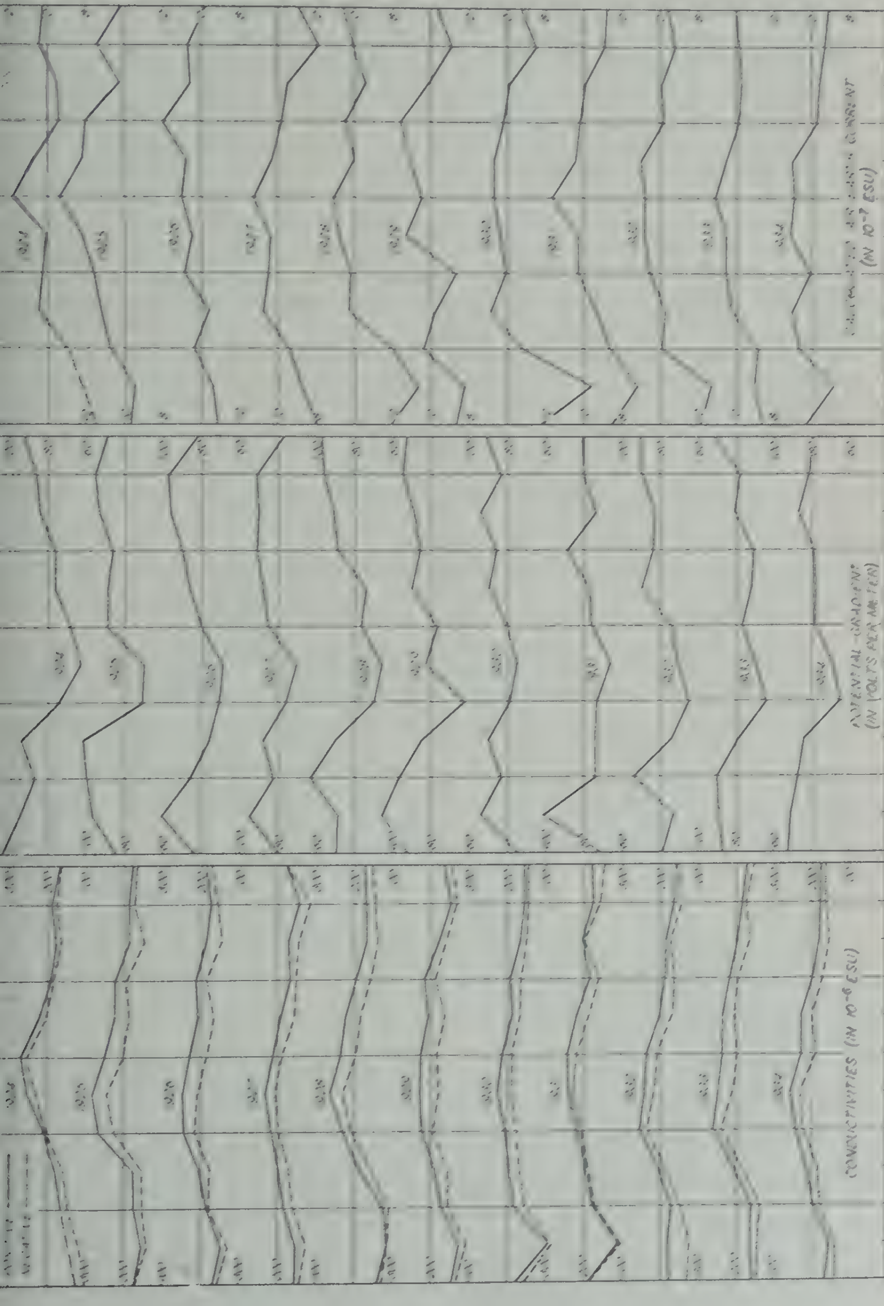


FIG. 7—ANNUAL VARIATION IN [illegible] 34, WATHEROO MAGNETIC OBSERVATORY, BASED ON SELECTED, LEAST-DISTURBED, FAIR WEATHER DAYS

The annual curves for calculated air-earth current are similar in character to those for the conductivities, with high values in the wet season and low in the dry. All three elements thus reflect the local atmospheric conditions at Watheroo through the year. The frequent fires over the surrounding region, in the months from November to March, furnish condensation-nuclei which, even on the selected non-smoky days under discussion, must remain at higher average concentrations than the nuclei of the wet season. These higher concentrations thus lower the concentrations of small ions and so cause lower conductivity or higher resistivity in the smoky months than in the other months of the year. The lowered air-earth current during the smoky season implies that this higher resistivity exists to relatively high levels in the air, which it must do to sufficiently affect the total resistance of the column of air over the Station. In the wet season nuclei are no longer supplied by local bush-fires but there are always some nuclei present, either brought in from distant regions or created by activities at the Observatory. However, these are kept to relatively low concentrations by the rains, so that it seems appropriate to find higher conductivities and also higher air-earth currents during the wet than during the dry smoky season.

Measurements of condensation-nuclei daily at 09^{h}, 120^{m} EMT, show that in the wet season the concentration at that hour generally ranges between 500 and 2000 per cc, whereas in the dry season the concentration averages higher, the values ranging between 2000 and 5000 per cc. Measurements on a few smoky afternoons have given concentrations of 20,000 to 30,000 per cc but such high values are rarely found at 9 o'clock.

The effect of smoke—After selecting the least-disturbed, fair-weather days for the months of November to March, of which there were 407 in the 11-year period, there remained 504 complete days which were almost without exception smoky days. Thus in that season of the year there were two large groups of data which could be contrasted for (1) days on which no smoke was noticeable, and (2) days disturbed by smoke. From these groups were prepared the two contrasting sets of diurnal-variation curves, for the different elements, which appear in Figure 8.

The potential-gradient is seen in Figure 8 to be much higher on smoky than on non-smoky days, while the conductivities are considerably lower. The calculated air-earth current, on the other hand, is essentially the same for smoky and non-smoky days, indicating that the decrease in conductivities on smoky days is largely confined to a relatively thin layer of air near the ground in which there occurs a corresponding increase in potential-gradient.

Comparing values of air-earth current for the various seasons of the year in Figure 7, it will be seen that during the smoky months of November to March the average values were lower than during the non-smoky months of May to August. This is in contrast to conditions over the oceans where higher air-earth current values occur during November to February than during May to August. It therefore seems evident that while on smoky days the day-to-day infusions of smoke appear to remain at low levels in the air, there is nevertheless a gradual accumulation of smoke even in higher levels during the smoky months, in sufficient quantity to increase the total resistance of the air-column and to decrease the current flowing in the column to a value lower than that for the wet season.

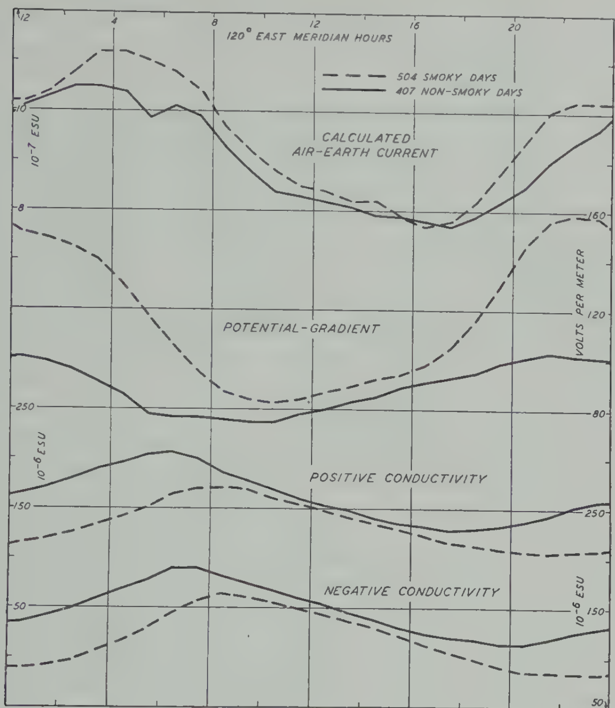


FIG. 8—SMOKE-EFFECT ON ATMOSPHERIC-ELECTRIC ELEMENTS IN HOT DRY SEASON, NOVEMBER TO MARCH, WATHEROO MAGNETIC OBSERVATORY, 1924-34

It will be noted in Figure 8 that the effect of the smoke on potential-gradient and conductivity is not uniform through the 24 hours, but is much greater in the night hours than in daylight. Careful notes taken through the years indicate that this should be the case. They indicate that on the great majority of smoky days the smoke is less noticeable, both by sight and by smell, in the daylight hours. Though the air may be quite smoky at sunrise, it usually becomes fairly clear by 09^h or 10^h and remains so until middle or late afternoon. Generally then there is little smoke noticeable in the late morning and midday hours on the so-called smoky days and it would be expected that during those hours the conductivities and potential-gradient would have values approaching those for non-smoky days. That they do so is seen in Figure 8. As there were included in the averages for the smoky days some days that remained smoky throughout the 24 hours, it is clear why the average values during daylight for the smoky days (see Fig. 8), can only approach and not equal the corresponding values for non-smoky days. On both smoky and non-smoky days the values of both positive and negative conductivities decrease gradually through the daylight hours to a minimum between 18^h and 22^h. This change is slow, however, and it may be assumed that ionic equilibrium is established at all times. If it is further assumed that the mobilities of the small ions and the magnitudes of the combining coefficients between small and large ions do not change through the day, then the decrease in conductivity (or small-ion content) in the

daylight hours must be due either to decrease in the rate of small-ion production or to an increase in concentration of condensation-nuclei, or to a combination of the two.

However, it is unlikely that a gradual increase of nuclei occurs through the daylight hours, for on most smoky days the smoke present at sunrise is dissipated soon afterward while that from any nearby bush-fire will, because of increased turbulence, have less chance than at night of getting to the Observatory. On non-smoky days the smoke-sources apparently are either extinguished or are sending their smoke away from, instead of toward, the Station, for there is no evidence of greater turbulence on those days. Rather than an increase in nuclei, a decrease might be expected through the day because convection-currents and high daytime wind-velocities would tend to mix the air near the ground with the air from higher levels containing fewer nuclei. Assuming that the nuclei are no more numerous in the daylight hours than at night, then the rate of small-ion production must be lower in the daylight hours than at night in order to account for the observed conductivity. That such is the case at Washington, D. C., has been shown by observations with a thin-walled chamber [6] and it seems reasonable to conclude that it may also be true at Watheroo. In either locality it is probable that in the night hours the ion-producing radioactive materials from the soil are kept in the lower levels of the atmosphere in the relatively stagnant air, and that in the daylight hours convection-currents distribute the radioactive materials to higher levels, thus reducing the quantity near the ground in the region where the atmospheric-electric measurements are made.

It is perhaps of interest to note in Figure 8 that the calculated air-earth current on smoky days is, almost throughout, higher than on the non-smoky days. The difference is not great, amounting only to about seven per cent, yet such a difference is found for each individual month of the smoky season and it is believed, therefore, to have some significance. It implies that the total resistance of the air-column at the Station is slightly less on smoky than on non-smoky days for it does not seem reasonable to draw the alternative conclusion that the total potential between the Earth and the upper conducting regions of the atmosphere is different on smoky than on non-smoky days. This suggests the possibility that on the so-called smoky days, smoke has settled to the ground from higher levels in the atmosphere and at the same time some of the particles composing the smoke have settled out of the air so that, on the whole, there are fewer particles in any vertical column than on the so-called non-smoky day.

Although both positive and negative conductivities undergo a decrease in value when smoke is present, owing to the combining of the small molecular ions—to which the conductivity is chiefly due—with the large particles composing the smoke, the negative conductivity is diminished more than the positive. This results in an increase in the ratio of positive to negative conductivity (λ_+/λ_-). Thus in Figure 9 the diurnal-variation curve for this ratio is higher for smoky than for non-smoky days. Furthermore, during the night hours when the greatest amount of smoke is present this ratio reaches its highest value (about 1.20), and it is lowest (about 1.00) during the daylight hours when there is less smoke. During the smoky season the diurnal-variation curve of the ratio resembles somewhat the curve for the potential-gradient. During the wet, non-smoky season this is not the case; there appears to be

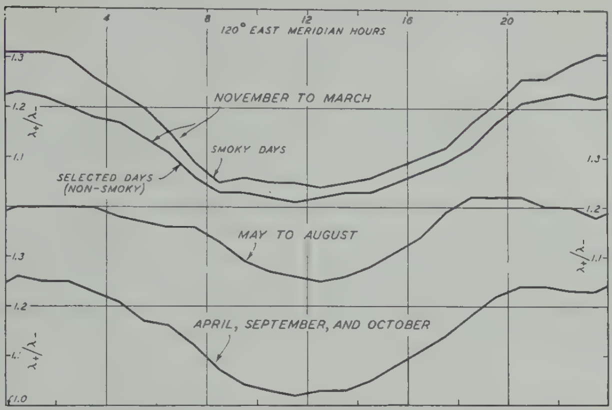


FIG. 9—SEASONAL DIFFERENCES IN DIURNAL VARIATION OF RATIO OF POSITIVE TO NEGATIVE CONDUCTIVITIES, WATHEROO MAGNETIC OBSERVATORY, 1924-34

practically no resemblance in the two curves. The potential-gradient curves differ very markedly in the two seasons while the ratio-curves differ but little.

Undoubtedly convection and turbulent action in the atmosphere play an important rôle in determining the character of the daily variation in the ratio (λ_+/λ_-). The seasonal curves for wind-velocity are shown in Figure 10. Regardless of season, the wind-velocity averages seven or eight miles per hour during the daylight hours and two to four miles per hour at night, and the change from high to low values, or the reverse, is very rapid. During the night hours when there is little mixing of the air, the normal positive electric field of the Earth can produce a marked depletion of the negative small-ion content near the ground (the so-called "electrode-effect"), resulting in a large value for the ratio of positive to negative conductivity. Conversely, during the daylight hours, when

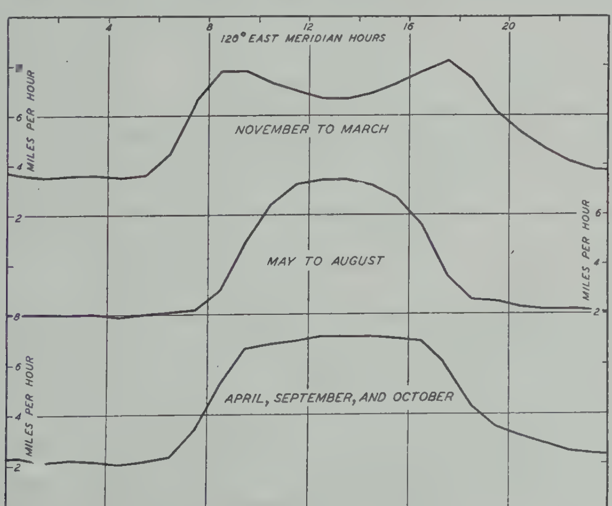


FIG. 10—SEASONAL DIFFERENCES IN CHARACTER OF DIURNAL VARIATION IN WIND-VELOCITY, WATHEROO MAGNETIC OBSERVATORY, 1930-34

there is considerable mixing of the air, a marked depletion of negative ions near the ground cannot be maintained by the electric field of the Earth, and consequently the ratio during this time of minimum electrode-effect will approach unity.

A theory regarding the electrode-effect, involving a relationship between the ratio of positive to negative conductivity, the electric field of the Earth, and the concentration of condensation-nuclei, has been developed by Scholz [4]. The important part played by the condensation-nuclei in the destruction of the small ions was recognized and the theory has been developed on the assumption that nuclei are uniformly distributed with height and are much more numerous than small ions. As suggested earlier some of the present data have been examined in connection with this theory. According to this theory, the ratio of positive to negative conductivity at a given height in the atmosphere is a function of the potential-gradient at that height and of the concentration of condensation-nuclei. Following considerations similar to those outlined by Gish and Sherman [7], who applied the theory to data from Fairbanks, Alaska, nuclei-concentrations have been computed for Watheroo for certain periods. Gish and Sherman concluded that the theory could be applied to the winter data from Fairbanks, when the wind-velocity did not exceed two and one-half miles per hour, and to such parts of the summer data as those for the night hours when the wind did not exceed four miles per hour. It was apparently not applicable to data for the daylight interval in summer when the wind-velocity usually was six to eight miles per hour. Conditions are, of course, different at Watheroo and it is not possible to predict the degree of turbulence there. It appears likely, however, that conditions at night are generally such that little turbulence exists and one may undertake to apply the theory of the electrode-effect to data obtained at night. During the daylight hours, on the other hand, it is probable that the theory will not apply.

In the application of the electrode-theory, values of potential-gradient and the corresponding values of the ratio of positive to negative conductivity were used to compute the concentration of condensation-nuclei (N_A) for each hour of the day for different periods of the year. The results were grouped under three time-intervals, namely, 00^h to 06^h, 07^h to 18^h, and 19^h to 24^h. Using the values of the nuclei thus computed with the corresponding observed value of positive conductivity, a value for q, the rate of small-ion production, was calculated for the three periods. It was necessary to make certain assumptions in making these computations. The mobility k of both positive and negative small ions was assumed to be the same and to be equal to 1.5 cm/sec/volt/cm. Also, it was assumed that the coefficient of combination of small ions with oppositely charged large ions was 5.4×10^{-6}, and with uncharged nuclei was 2.7×10^{-6}. It was further assumed that the effective height at which potential-gradient measurements were made was 50 cm, while that at which the conductivities were measured was 200 cm. The results of the calculation are shown in Table 2.

As seen from Table 2, the value of q for any period is higher during the daylight interval of 07^h to 18^h than during either of the intervals at night. The value of q at Washington as previously mentioned [6], is considerably lower during the interval of daylight than at night and there is good reason to expect that q at Watheroo should follow a similar course.

It seems likely, therefore, that during the interval of daylight, the computed values of q are in error and should be lower than those given in Table 2.

This failure of the theory was expected since the daylight wind-velocity is six to eight miles per hour. It seems safe to assume that lower values of q prevail at Watheroo during the daylight hours than at night and that the diurnal-variation curve there does not differ greatly from that for Washington. If, then, one leaves the values for the intervals 00^h to 06^h and 19^h to 24^h unadjusted while the values for the interval 07^h to 18^h are halved, a close approximation to the Washington daily curve for q will result. One must, however, under these circumstances, halve the corresponding values of N_A. This adjustment gives a daily variation in N_A more in accord with what one might expect, since there is reason to believe that the nuclei-values diminish as the wind increases in velocity, and also since the observers note, in general, much less smoke during the middle of the day than during the night and early morning.

TABLE 2—*Computations of N_A and q from application of Scholz's theory of electrode-effect to atmospheric-electric data for Watheroo Magnetic Observatory, 1924-34*

Group of days	Period					
	00^h-06^h		07^h-18^h		19^h-24^h	
	N_A *per cc*	q in *ion-pairs/cc/sec*	N_A *per cc*	q in *ion-pairs/cc/sec*	N_A *per cc*	q in *ion-pairs/cc/sec*
ber-March, selected (non-smoky) days	4120	9.4	6530	13.1	4460	7.9
ber-March, smoky days	5310	8.7	6070	11.3	5730	7.8
ugust, selected days	5350	10.4	4530	12.9	3100	8.3

It was stated earlier in the paper that an attempt would be made to account for the unusual character of the potential-gradient diurnal variation during the wet months of May to September (see Figs. 2, 3, and 6). To secure information regarding the factors on which the potential-gradient depends, data at Watheroo for 1929 have been used in conjunction with measurements made over the Pacific Ocean during Cruise VII of the *Carnegie* in 1929 [8]. Although data for several months are available, the two months of January and May give essentially the same results as the other months and the discussion will be confined to them. Both conductivity and potential-gradient were measured at Watheroo and over the Pacific Ocean during these months but not necessarily on identical days. The diurnal-variation curves of the various elements employed in the calculation are plotted in the last two panels of Figure 11. It should be noted that the mean value of the conductivity over the oceans was derived from only daily measurements in the two months and the diurnal variation was assumed to be non-existent, which appears justifiable on the basis of many diurnal-variation series made over the oceans at other times. From each mean hourly value of potential-gradient and corresponding value of total conductivity (positive plus negative) an hourly value of air-earth current was computed. The resulting 24-hour curves of current for both Watheroo and the oceans, for the two months, are given in the lower part of Figure 11. Assuming, as

others have done in previous discussions [9, 10], that the total potential between the Earth and the upper conducting layer is at any instant the same at Watheroo and at any oceanic station, then the ratio of total resistance of the air-column over Watheroo to that over the ocean equals the ratio of the air-earth current over the ocean to that at Watheroo. That is, $(R_w/R_o)=(i_o/i_w)$ where R_w and R_o represent the total effective resistance of the air-column above Watheroo and above an oceanic station, respectively, while i_w and i_o are the corresponding air-earth currents at Watheroo and over the ocean, respectively.

There is abundant reason for regarding R_o as constant through the day; therefore the diurnal-variation curve for the ratio (R_w/R_o) is due to and represents the character of diurnal variation in R_w. Hourly values of this ratio for the two months January and May are given in Figure 11. A smoothed free-hand curve has been drawn through the derived curve for January to represent the average diurnal variation in that month, and the same smoothed curve has been applied to the results in May, where, as may be seen, it fits the points remarkably well. In other words, it appears that the character of diurnal variation in the total resistance between ground and the upper conducting layer is essentially the same in May as in January at Watheroo, and since other months of the year that have been examined are not greatly different, it seems justifiable to conclude that the character of diurnal variation in R_w remains essentially constant throughout the year.

Attention must be called to the fact that the conductivity at Watheroo during January, 1929, did not vary through the day in the usual manner for this time of year (see 11-year average for January in Fig. 1). The maximum in the diurnal-variation curve of conductivity for the 11-year period falls between 06^h and 07^h, 120° EMT, while for January, 1929, it falls between 09^h and 10^h. This unusual behavior of the conductivity in January, 1929, may be attributed, it is believed, to the unusual behavior of the wind during this month. Usually the wind is relatively calm at night and rises to considerable velocities during the daytime. In January, 1929, however, the average wind-velocity was relatively high also during the night. The influence of this behavior of the wind upon the conducting diurnal variation has been investigated with the aid of data for November, 1928. These data were separated into two groups according to whether the wind was high or low at night, and the atmospheric-electric elements were meaned for each group. The results of this survey are summarized as curves in the first and second panels of Figure 11. Comparing one group with the other, it is seen that only the conductivity shows any outstanding difference in character. The diurnal variation in this element in one case agrees well with that found for January and in the other case with that found for May, depending upon whether the wind remained high at night or whether it diminished to low values. In the case of May, and one group of data in November, the wind dropped to low values at night and the maximum in the conductivity for these groups of data occurred during the early morning hours. For January and the other November group the wind remained high at night and the maximum conductivity occurred several hours later. That there should be a connection between the behavior of the wind and conductivity is not surprising. The conductivity of the upper layers of the atmosphere [reciprocal of (i_o/i_w)] undergoes a characteristic diurnal variation with a

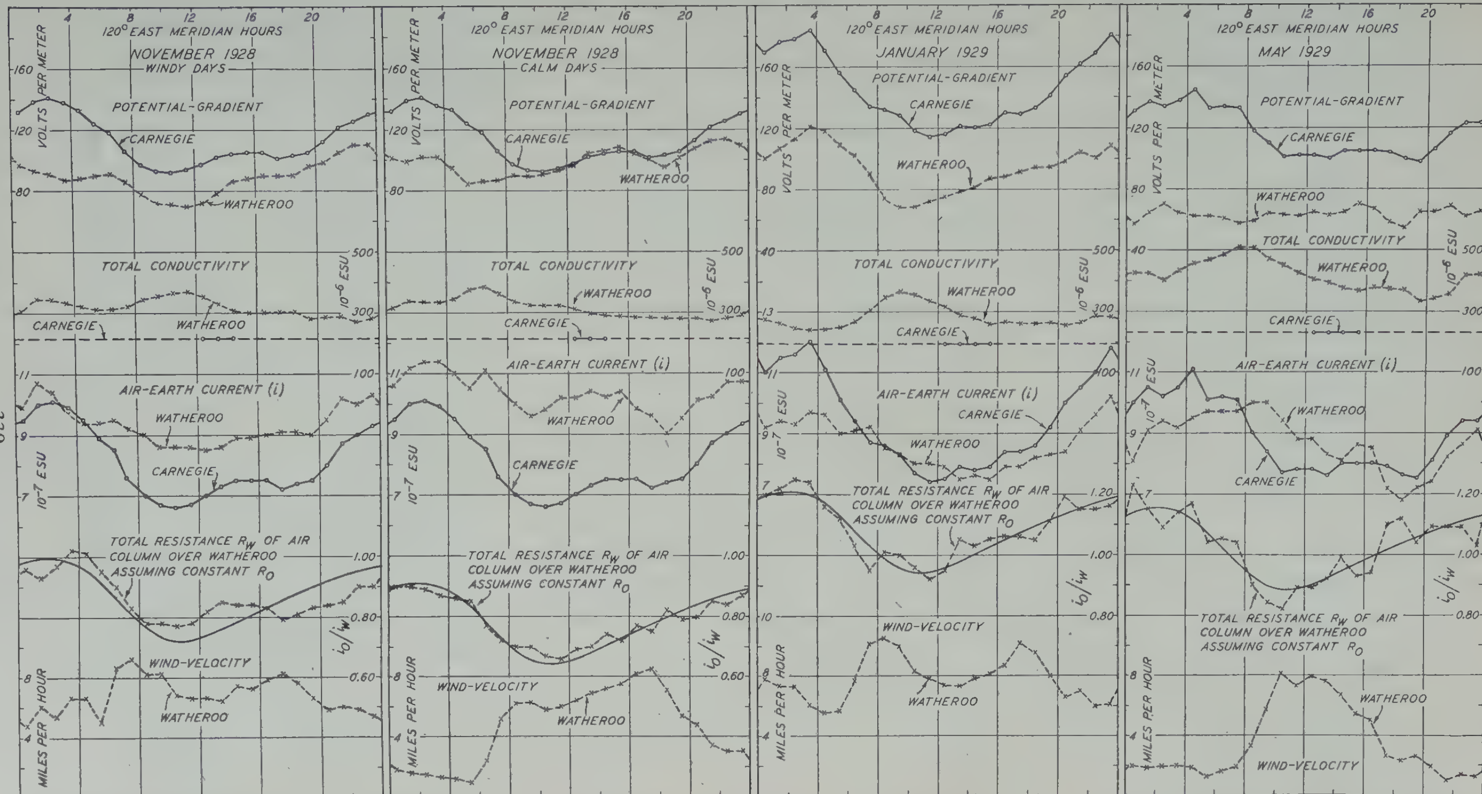


FIG. 11—DIURNAL VARIATION IN TOTAL RESISTANCE OF AIR-COLUMN, WATHEROO (ALIKE DURING DRY AND WET SEASONS, YET THE DIURNAL VARIATION IN POTENTIAL-GRADIENT DIFFERS GREATLY)

maximum around 10^h, local time. When the wind is low at night, the change in conductivity of the upper atmosphere cannot influence the conductivity of the layer near the ground. On the other hand, when the wind is high at night, considerable mixing between the upper and lower levels is maintained so that, as changes occur in conductivity of the upper layers, more or less corresponding changes will be brought about in the conductivity of the lower levels. The maximum in the lower-layer conductivity thus tends to occur at the same time as that in the upper layers, that is, at about 10^h and not at 05^h or 06^h as is usually the case. This is brought out in Figure 12 where there are plotted diurnal-variation

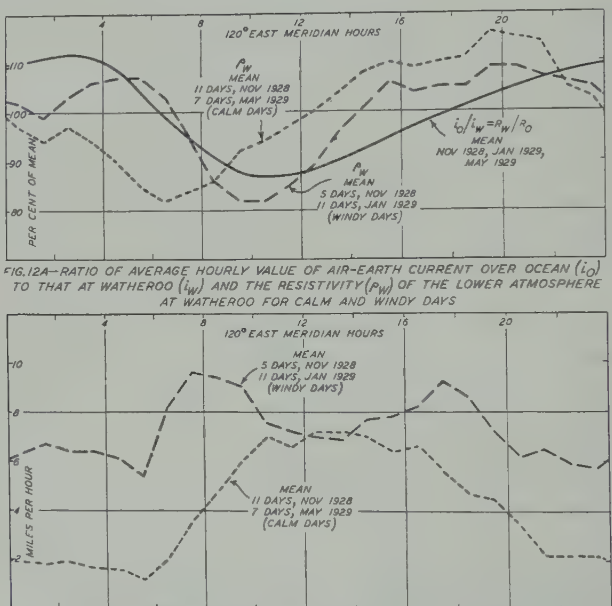


FIG. 12A—RATIO OF AVERAGE HOURLY VALUE OF AIR-EARTH CURRENT OVER OCEAN (i_O) TO THAT AT WATHEROO (i_W) AND THE RESISTIVITY (ρ_W) OF THE LOWER ATMOSPHERE AT WATHEROO FOR CALM AND WINDY DAYS

FIG. 12B—DIURNAL VARIATION IN WIND-VELOCITY AT WATHEROO

curves for the ratio (R_w/R_o), and the specific resistance (ρ_w) of the lower levels for both calm and windy conditions at night. As is readily seen, when the wind was high during both day and night, the resistivity curve (ρ_w) underwent a diurnal variation similar in character to that for the total resistance (R_w/R_o). On the other hand, when the wind did not remain high at night, the minimum in the resistivity-curve (corresponding to a maximum in the conductivity-curve) was reached earlier. An explanation for the latter type of variation in conductivity, the normal type, has already been suggested.

The values of the ratio (i_o/i_w), as previously explained, show a diurnal variation at Watheroo, the character of which is essentially unchanged throughout the year. This variation is regarded as representing the variation in total resistance of a vertical air-column over the Station. One is tempted to speculate concerning possible causes for this variation. It is believed, however, that too little is yet known about the element and

its variations at different localities to justify much speculation at this time.

The diurnal variation in the resistance has already been obtained for the very northern station at Fairbanks, Alaska, by Gish and Sherman [7]. Little variation was found at this Station during the winter season, while during the summer the variation was about as great as that found for Watheroo and not entirely dissimilar.

For two other localities there are available unpublished results of studies of the diurnal variation in the ratio, or total resistance, which may be briefly presented here and compared with the results for Watheroo. One of these is the Huancayo Magnetic Observatory of the Department of Terrestrial Magnetism of the Carnegie Institution of

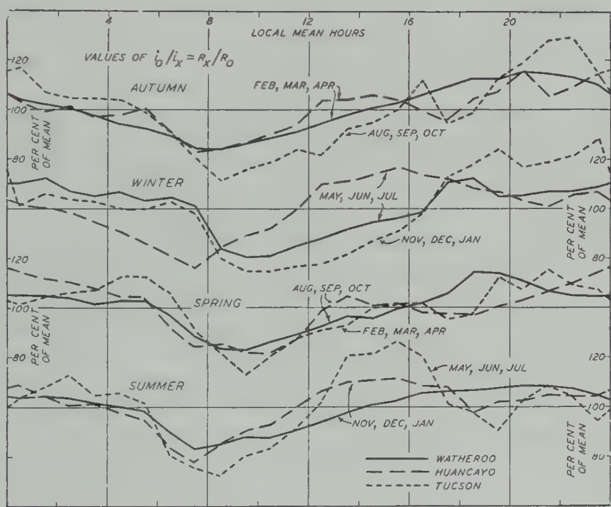


FIG. 13—RATIO OF AIR-EARTH CURRENT OVER OCEAN (1915-21) TO THAT AT WATHEROO (1924-34), HUANCAYO (1924-34), AND TUCSON (1931)

Washington which is located at Huancayo, Peru, and the other is the Tucson Magnetic Observatory of the United States Coast and Geodetic Survey, at Tucson, Arizona. The instruments used for measuring the atmospheric-electric elements were essentially the same at Watheroo, Huancayo, and Tucson. The values of the air-earth current for Huancayo were computed from monthly mean hourly values of gradient and positive and negative conductivities for the 11-year period 1924-34. Those for Tucson were computed also from monthly mean hourly values of gradient and the conductivities, but for the year 1931 only. Values of air-earth current over the ocean for use with the data for Huancayo and Tucson were derived from oceanic data obtained in the years 1915-21. Diurnal-variation curves for the ratio (i_o/i_x), for different seasons, are shown in Figure 13 for the three stations, Watheroo, Huancayo, and Tucson. In general, the three curves show considerable similarity in that all pass through a minimum during the forenoon and then rise to higher values later in the day. The curves for all three stations show approxi-

mately the same range when plotted as "per-cent-of-mean value." The mean absolute values differ considerably, however, as may be seen from Table 3, where are also given the mean values from Fairbanks. The fact that the ranges in variation of total resistance at Watheroo, Huancayo,

TABLE 3—*Ratio of air-earth current over the ocean (i_o) to that at the indicated land-station (i_x)*

Station	Values of ratio (i_o/i_x)			
	Autumn	Winter	Spring	Summer
Watheroo	1.22	0.85	1.06	1.24
Huancayo	1.06	1.03	1.10	1.07
Tucson	1.81	1.80	1.70	1.50
Fairbanks	....	1.11	....	1.16

Tucson, and during the summer at Fairbanks, are so similar when plotted on the basis of per-cent-of-mean value, while the ratios at the same time have such widely different absolute values, may prove of importance in any consideration of possible causes of the variation. Any theory presented to explain the diurnal variation in the total resistance must be in accord with these findings, and with others brought out in the present discussion. The diurnal variation in the resistance must be a "local-time" rather than a "universal-time" phenomenon. It appears to be present to some extent over all the land-stations discussed here but apparently does not exist over the ocean since the potential-gradient there shows practically no local-time effect. It would be extremely helpful toward building a theory to secure evidence regarding the behavior of the resistance at still other locations. Such additional work seems vital in fully establishing the validity of systematic variations in total resistance similar to those discussed here.

References

[1] O. W. Torreson, Terrestrial Magnetism and Electricity, Physics of the Earth, **8**, 241-252, New York, McGraw-Hill Book Co. (1939).
[2] W. F. G. Swann and S. J. Mauchly, Terr. Mag., **22**, 1-21 (1917).
[3] S. J. Mauchly, J. Optical Soc. Amer., **6**, 852-858 (1922).
[4] J. Scholz, Wien, SitzBer. Ak. Wiss. IIa, **140**, 49-66 (1931).
[5] S. J. Mauchly, Terr. Mag., **28**, 61-81 (1923).
[6] G. R. Wait, Carnegie Inst., News Service Bull., **3**, 87-91 (1934); A. G. McNish and G. R. Wait, Phys. Rev., **47**, 785-786 (1935).
[7] O. H. Gish and K. L. Sherman, Terr. Mag., **45**, 173-190 (1940).
[8] W. C. Parkinson and O. W. Torreson, C.-R. Assemblée Stockholm, 1930; Union Géod. Géophys. Internat., Sec. Mag. Electr. Terr., Bull. No. 8, 340-345 (1931).
[9] F. J. W. Whipple, Rep. Brit. Ass. 352 (1931).
[10] F. J. Scrase, London, Met. Office, Geophys. Mem., No. 60 (1934).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
Carnegie Institution of Washington,
Washington, D. C.

K-INDEX ACCORDING TO THE U.S.S.R. OBSERVATORIES

By N. P. Benkova and O. Y. Kosuhia

In accordance with the resolution of the Washington Assembly of the International Association of Terrestrial Magnetism and Electricity in September, 1939, the Sloutzk Magnetic Observatory began to tabulate magnetic disturbances by means of the index K. Following the suggestion of the Association a K-scale was adopted according to which the intervals with an amplitude greater than 600 gammas were gaged by the index $K=9$. Comparison of the Sloutzk and Niemegk frequency-occurrences of K-indices shows that the choice of such a scale was quite favorable. Table 1 gives the frequency-distribution of K for these two observatories during January and February, 1938.

Table 1

Month	Observatory	For $K=$									
		0	1	2	3	4	5	6	7	8	9
1938											
Jan.	Sloutzk	7	41	58	55	34	28	12	5	3	4
	Niemegk	13	35	63	57	36	28	9	2	4	1
Feb.	Sloutzk	13	35	62	60	37	10	4	2	..	..
	Niemegk	16	35	63	63	30	13	4	..	..	..

The values of K for Sloutzk agree quite well with the average international index K_m[1]. Correlation-coefficient, r, for the same months is $r(K, K_m)=0.90$. Linear relationship is $K_m=0.84K+0.07$. Probable error is $\rho(\triangle K_m)=0.46$.

Since January, 1940, K-indices from Sloutzk are published in the *Cosmical Data Review* by the Institute of Terrestrial Magnetism. Beginning January, 1941, other observatories of the U.S.S.R., namely, Wyssokaya Doubrawa, Sajmistche, Zouy, Nijnedewitzck, Stepanovka, Doucheti, and Tashkent, have gaged disturbances by means of the K-index. Comparison of the K-indices for eight observatories of the U.S.S.R. shows the choice of scales at all to be satisfactory.

Frequency-distribution for all the observatories for January, 1941, is given in Table 2.

Table 2

Observatory	$K=$							
	0	1	2	3	4	5	6	7
Sloutzk	13	31	82	63	38	18	2	1
Wyssokaya Doubrawa	22	45	84	52	30	12	2	1
Sajmistche	36	43	66	59	28	13	2	1
Zouy	13	45	78	70	34	6	2	..
Nijnedewitzck	16	35	80	58	31	15	5	1
Stepanovka	13	46	91	59	27	12	..	..
Doucheti	3	29	85	99	22	10	..	..
Tashkent	5	23	75	88	38	17	2	..

[1]See Terr. Mag., **44**, 411-454 (1939).

From the K-indices for the eight observatories were computed an average index, K_u, and daily index, B, as in Table 3. The correlation-

TABLE 3—*Daily index B for eight observatories U.S.S.R. January and February, 1941*

Date	Jan.	Feb.	Date	Jan.	Feb.	Date	Jan.	Feb.
1	6	4	12	5	4	23	7	8
2	2	5	13	4	8	24	8	7
3	3	7	14	3	7	25	7	7
4	4	5	15	3	7	26	6	6
5	3	6	16	5	5	27	7	3
6	5	7	17	9	7	28	5	5
7	6	7	18	7	4	29	4	..
8	4	7	19	7	4	30	6	..
9	6	5	20	5	6	31	3	..
10	5	5	21	4	9			
11	5	4	22	4	9			

coefficient for January, 1941, between K_u and K_A (an average K-index normalized to represent world-wide conditions from seven American-operated observatories) is $r(K_u, K_A)=0.80$.

A high correlation was found to exist between the index B and the magnetic character-figure C_u, the latter being the average of the daily character-figures from 16 observatories of the U.S.S.R. The correlation-coefficient between B and C_u is $r(B, C_u)=0.98$. If in computing the average figure C_u, only values from the eight observatories listed in Table 2 are used, the correlation-coefficient decreases to 0.95.

INSTITUTE OF TERRESTRIAL MAGNETISM,
Sloutzk, U.S.S.R., May 26, 1941

INTERNATIONALE ERDMAGNETISCHE CHARAKTERZAHLEN IM JAHRE 1940

VON J. BARTELS

TABELLE 1—*Mittlere erdmagnetische Charakterzahlen für jeden Tag des Jahres* 1940 *nach Angaben der Observatorien*

Monat	Tag															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1940																
Jan.	0.5	0.8	1.8	1.3	0.8	1.2	1.2	0.6	1.0	1.5	1.4	1.2	0.3	0.2	0.3	0.8
Feb.	1.6	1.0	1.1	0.6	0.6	1.1	0.9	0.7	0.5	0.5	0.8	1.1	0.7	0.3	0.4	0.5
März	0.3	0.1	0.4	0.2	0.1	0.0	0.1	0.8	1.1	0.2	0.1	1.0	0.6	0.5	0.0	0.4
Apr.	1.7	1.4	1.9	1.1	0.7	0.4	0.0	0.1	0.1	0.0	0.3	0.1	0.4	0.6	1.0	0.8
Mai	0.4	0.3	0.2	0.1	0.2	0.0	0.3	0.2	0.6	1.1	1.0	1.1	0.6	0.8	0.9	0.4
Juni	0.1	0.5	0.5	0.2	0.7	1.3	1.2	1.0	0.9	0.3	0.2	0.3	0.3	1.5	1.3	0.9
Juli	0.5	0.2	0.9	1.2	0.9	0.7	0.3	0.3	0.9	1.2	0.6	0.2	1.7	1.2	0.7	0.4
Aug.	0.7	0.8	1.4	0.5	0.7	1.0	0.8	0.7	1.6	0.6	0.9	0.6	0.4	0.4	0.1	0.1
Sep.	1.2	0.8	1.1	0.9	0.6	0.5	1.2	0.9	0.8	0.1	0.2	0.1	0.2	1.1	0.7	0.8
Okt.	1.6	0.9	1.0	0.5	0.5	0.9	1.7	1.3	0.4	0.4	0.5	0.5	0.1	0.0	0.8	0.8
Nov.	0.7	0.3	0.6	1.2	1.1	0.4	0.5	0.1	0.8	0.1	0.1	1.0	1.4	1.0	0.7	1.1
Dez.	0.7	1.2	1.0	0.7	0.4	0.2	0.0	0.0	0.6	0.8	0.6	0.7	0.6	1.0	0.8	0.6

Monat	Tag															Mittel
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1940																
Jan.	1.2	1.7	0.5	0.5	0.1	0.7	0.5	0.9	0.9	0.2	0.2	0.0	0.9	1.2	1.5	0.84
Feb.	0.2	0.0	0.1	1.0	1.0	0.6	0.6	0.9	1.6	0.7	0.3	0.3	0.8			0.71
März	0.1	0.0	1.2	1.3	0.7	0.6	1.5	2.0	2.0	1.6	1.3	1.1	1.9	2.0	1.9	0.81
Apr.	0.3	0.1	0.3	0.8	0.9	1.0	0.5	0.4	1.8	1.4	0.8	0.6	0.5	0.8		0.69
Mai	0.7	1.5	0.7	0.7	0.6	1.3	1.2	1.8	0.8	1.3	1.0	0.9	0.4	0.1	0.0	0.68
Juni	0.8	1.0	0.7	0.1	0.1	0.8	0.4	1.0	2.0	1.3	0.5	0.5	0.5	0.8		0.72
Juli	0.2	0.1	0.3	0.2	0.6	0.9	0.4	0.7	0.5	0.3	0.2	0.3	0.5	1.1	1.0	0.62
Aug.	0.1	1.0	0.8	0.7	0.4	0.7	0.3	0.0	0.3	1.1	0.9	0.8	0.5	0.2	0.5	0.63
Sep.	0.1	0.1	0.1	0.8	0.9	0.5	0.0	0.1	1.1	1.7	1.5	1.4	0.8	0.7		0.70
Okt.	0.4	0.8	1.0	0.6	1.1	0.9	0.0	0.0	1.1	1.4	1.1	0.7	0.3	0.2	0.4	0.71
Nov.	1.0	0.3	0.3	0.7	1.1	1.2	1.1	0.4	1.7	1.2	0.8	0.4	1.5	0.9		0.79
Dez.	0.6	0.4	0.3	1.7	1.5	1.2	1.2	0.5	0.8	0.8	0.7	0.9	1.1	1.4	1.3	0.78
																0.723

Terr. Mag., **33**, 203 (1928); **34**, 207 (1929); **35**, 178 (1930); **36**, 255 (1931); **37**, 259 (1932); **38**, 301-302 (1933); **39**, 237-238 (1934); **40**, 383-384 (1935); **41**, 351-352 (1936); **42**, 395-396 (1937); **43**, 471-472 (1938); **44**, 391-393 (1939); **45**, 351-352 (1940).

Tabelle 2—*Erdmagnetisch ruhige und gestörte Tage im Jahre 1940*

Monat	Ruhige Tage						Gestörte Tage				
1940											
Jan.	(0.14)	**14,**	**21,**	**26,**	**27,**	**28**	**3** (1.8),	**10** (1.5),	**11** (1.4),	**18** (1.7),	**31**
Feb.	(0.18)	**14,**	**17,**	**18,**	**19,**	**27**	**1** (1.6),	**2** (1.0),	**3** (1.1),	**12** (1.1),	**25**
März	(0.04)	**6,**	**7,**	**11,**	**15,**	**18**	**24** (2.0),	**25** (2.0),	**29** (1.9),	**30** (2.0),	**31**
Apr.	(0.06)	**7,**	**8,**	**9,**	**10,**	**12**	**1** (1.7),	**2** (1.4),	**3** (1.9),	**25** (1.8),	**26**
Mai	(0.08)	**3,**	**4,**	**6,**	**30,**	**31**	**18** (1.5),	**22** (1.3),	**23** (1.2),	**24** (1.8),	**26**
Juni	(0.14)	**1,**	**4,**	**11,**	**20,**	**21**	**6** (1.3),	**7** (1.2),	**14** (1.5),	**15** (1.3),	**25**
Juli	(0.18)	**2,**	**17,**	**18,**	**20,**	**27**	**4** (1.2),	**10** (1.2),	**13** (1.7),	**14** (1.2),	**30**
Aug.	(0.10)	**15,**	**16,**	**17,**	**24,**	**30**	**3** (1.4),	**6** (1.0),	**9** (1.6),	**11** (0.9),	**26**
Sep.	(0.08)	**10,**	**12,**	**17,**	**19,**	**23**	**1** (1.2),	**7** (1.2),	**26** (1.7),	**27** (1.5),	**28**
Okt.	(0.06)	**13,**	**14,**	**23,**	**24,**	**30**	**1** (1.6),	**7** (1.7),	**8** (1.3),	**25** (1.1),	**26**
Nov.	(0.18)	**8,**	**10,**	**11,**	**18,**	**19**	**12** (1.0),	**13** (1.4),	**22** (1.2),	**25** (1.7),	**29**
Dez.	(0.18)	**6,**	**7,**	**8,**	**18,**	**19**	**20** (1.7),	**21** (1.5),	**22** (1.2),	**30** (1.4),	**31**

Zur Reproduktion werden vorgeschlagan:

**1940—März 24 u. 29; September 26, 15 Uhr bis September 27, 9 Uhr.
*1940—Januar 3; April 2 u. 25; Juni 25; Juli 13; August 3; Oktober 7 u. 8; November 25.

Zahl der Observatorien, deren Charakter-Schätzungen verwendet werden konnten: 53 im Januar und Februar; 54 im März; 56 im April, Mai, Juni; 58 im Juli; 57 im August bis November; 58 im Dezember.

Geophysikalisches Institut,
Potsdam, August 1941

THE IONOSPHERE AT WATHEROO, WESTERN AUSTRALIA, APRIL TO JUNE, 1941

By W. C. Parkinson

This report is a continuation of those already published in this Journal[1] and gives monthly mean hourly values of the heights and penetration-frequencies of the ionosphere as obtained by means of automatic multifrequency ionospheric recording apparatus located near Watheroo, Western Australia, in latitude 30° 19′.1 south, longitude 115° 52′.6 east of Greenwich, which operates over the frequency-range 0.516 to 16.0 Mc/sec.

Table 1 gives the monthly mean hourly values of the height of maximum electron-density (h^{max}), uncorrected for retardation in lower regions[2], and the minimum virtual height (h^{min}) for both the F_1- and F_2-regions, the penetration-frequencies for the E-, F_1-, and F_2-regions, and the lowest frequency at which echoes were observed when that frequency was higher than 0.516 Mc/sec.

Table 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, April to June, 1941*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				April, 1941				
00			326	261			3.83	
01			314	250			3.85	
02			314	249			3.75	
03			302	244			3.73	
04			294	235			3.56	
05			312	240			3.18	
06			307	245	(1.22)		3.22	(0.50)
07			267	238	1.90		5.46	0.66
08	232	230	257	244	2.49	3.82	6.91	0.73
09	225	222	266	250	2.86	4.17	7.73	0.75
10	223	215	270	258	3.03	4.44	8.18	0.83
11	211	206	278	268	3.16	4.50	8.23	0.86
12	216	208	293	276	3.23	4.54	8.21	0.85
13	230	215	302	286	3.20	4.62	8.47	0.88
14	239	228	299	279	3.14	4.50	8.87	0.82
15	237	230	285	261	2.89	4.18	9.18	0.76
16	232	230	273	244	2.58	3.74	8.70	0.72
17			268	228	2.01		8.25	0.66
18			269	214	(1.64)		6.57	(0.51)
19			295	224			4.71	
20			316	246			3.95	
21			320	252			3.94	
22			334	256			3.84	
23			330	259			3.89	

[1]Terr. Mag., **44**, 199-204 and 341-343 (1939); **45**, 45-47, 169-172, and 471-476 (1940); **46**, 79-82, 223-229 (1941).

[2]Phys. Rev., **57**, 87-94 (1940).

Table 1—*Mean hourly values of ionospheric data, Watheroo Magnetic Observatory, April to June, 1941—Continued*

120° east mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^{0}_{E}	$f^{0}_{F_1}$	$f^{0}_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				May, 1941				
00			320	257			3.49	
01			315	247			3.58	
02			304	238			3.69	
03			303	242			3.72	
04			281	229			3.83	
05			280	219			3.36	
06			287	223			3.05	
07			249	217	1.78		4.68	0.55
08	(220)	(203)	248	225	2.37	(2.93)	6.02	0.66
09	229	222	251	242	2.74	3.96	6.71	0.70
10	225	219	268	256	2.96	4.23	7.48	0.76
11	224	215	260	249	3.11	4.30	7.85	0.79
12	218	213	276	255	3.10	4.37	7.47	0.79
13	223	211	288	269	3.08	4.37	7.40	0.76
14	230	218	286	265	3.00	4.25	8.02	0.75
15	230	219	276	249	2.76	3.93	8.03	0.72
16	(229)	(227)	262	233	2.42	(3.39)	7.64	0.68
17			257	214	1.70		6.67	0.64
18			265	204	(1.30)		4.98	(0.65)
19			277	220			3.46	
20			288	232			3.07	
21			306	247			3.04	
22			319	250			3.26	
23			325	251			3.34	
				June, 1941				
00			321	249			3.46	
01			321	246			3.70	
02			305	238			3.79	
03			306	236			3.99	
04			290	232			4.05	
05			281	220			3.80	
06			286	221			3.25	
07			255	223	1.52		4.19	0.53
08	230	220	244	222	2.28	(2.70)	5.70	0.70
09	218	212	255	234	2.57	3.59	6.30	0.72
10	229	219	256	246	2.90	4.14	7.02	0.77
11	220	210	257	246	3.00	4.26	6.95	0.77
12	225	207	272	263	3.04	4.38	7.02	0.81
13	224	216	276	273	3.03	4.36	7.13	0.81
14	217	211	272	254	2.96	4.10	7.22	0.76
15	227	220	270	250	2.74	3.79	7.38	0.73
16	225	225	260	232	2.33	(3.30)	7.02	0.66
17			255	220	1.65		6.92	0.63
18			262	208			4.81	
19			276	222			3.47	
20			274	224			3.26	
21			295	234			3.24	
22			304	237			3.47	
23			319	243			3.48	

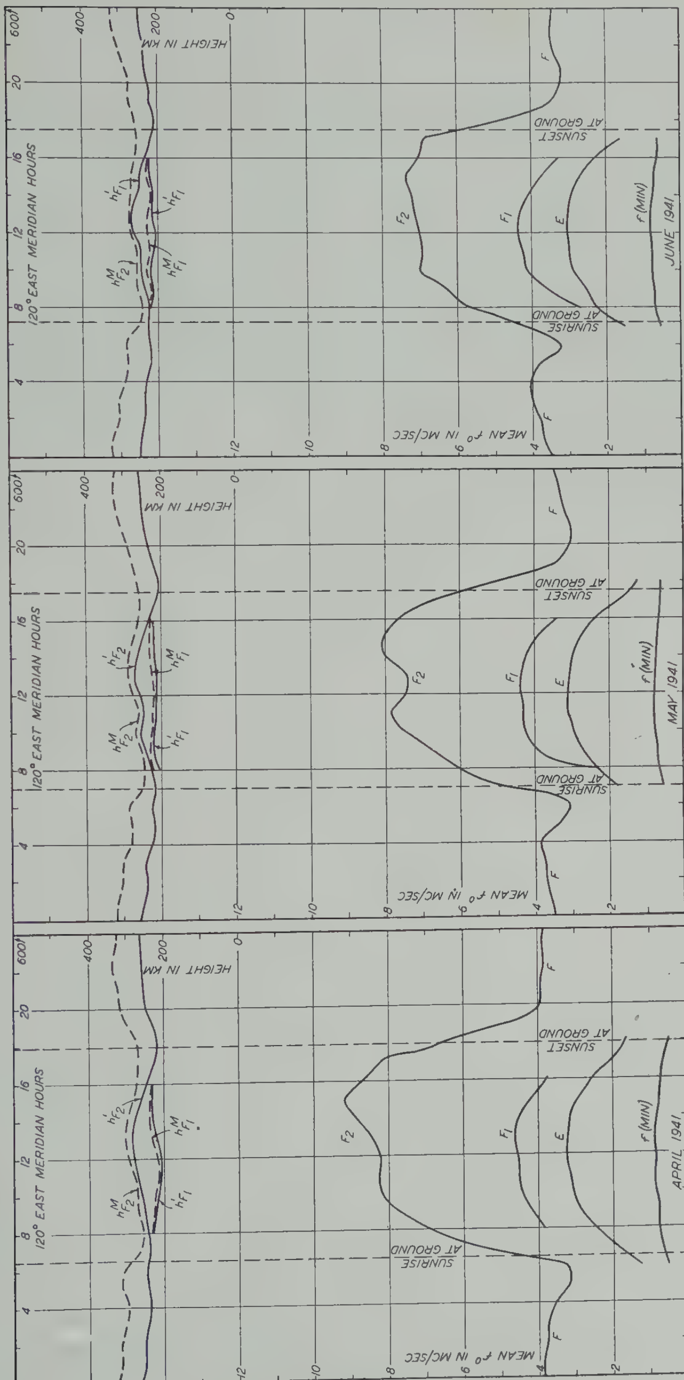


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, APRIL, MAY, AND JUNE, 1941, WATHEROO, WESTERN AUSTRALIA

These mean values are shown graphically in Figure 1 as a series of diurnal-variation curves. The single layer existing during the night is considered as the F_2-layer.

The curves of F_2-layer critical frequency show the same general shape as those for the corresponding months of previous years, except that the decrease near sunset is more sudden, especially for April. Values are systematically lower than those for 1940 by about ten per cent. Heights are, in general, slightly lower than in 1940.

F_1- and E-layer critical frequencies show the usual diurnal variation and expected decrease in value.

Values of the minimum frequency at which echoes are received give a measure of the absorption in the lower layers (below the E-layer). They continue to show little seasonal or diurnal variation.

The period from April 24 to May 2, two solar rotations after the magnetic storm of March 1, showed somewhat disturbed ionospheric conditions; otherwise there was little unusual activity. No fade-outs were observed during the quarter.

Watheroo Magnetic Observatory,
Watheroo, Western Australia, July 20, 1941

THE IONOSPHERE AT HUANCAYO, PERU, APRIL TO JUNE, 1941

By P. G. Ledig, R. C. Coile, and M. W. Jones

This report is a continuation of those already published in this Journal[1] and gives monthly mean hourly values of the heights and penetration-frequencies of the ionospheric regions as obtained from the automatic multifrequency ionospheric recording apparatus located near Huancayo, Peru, South America, in latitude 12° 02′.7 south, longitude 75° 20′.4 west of Greenwich, which operates over a frequency-range 0.516 to 16.0 Mc/sec. A complete discussion of these data will be made in an annual summary.

Table 1 gives the monthly mean hourly values of the actual heights of maximum electron-density (h^{max}), uncorrected for retardation in

Table 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, April to June, 1941*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^0_E	$f^0_{F_1}$	$f^0_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				April, 1941				
00			308	239			7.88	
01			303	235			7.38	
02			301	241			5.98	
03			305	256			4.70	
04			302	263			3.85	
05			305	278	0.75		3.29	0.66
06			322	280	1.36		4.60	0.73
07			314	261	2.36		7.64	0.82
08	261	243	368	295	2.82	4.71	9.22	1.02
09	248	237	419	323	3.30	4.85	9.61	1.14
10	240	232	451	343	3.65	4.88	9.45	1.28
11	235	228	460	363	3.87	4.89	8.80	1.50
12	232	227	451	365	3.92	4.88	8.62	1.54
13	230	227	442	355	3.82	4.83	9.02	1.48
14	235	225	435	337	3.69	4.78	9.54	1.35
15	247	219	437	322	3.08	4.66	9.89	1.17
16	276	235	440	279	2.77	4.56	9.91	1.10
17			455	273	2.19		9.84	0.97
18			467	297	1.09		9.46	0.71
19			483	342	0.84		8.53	0.69
20			434	322			8.44	
21			373	281			8.68	
22			333	247			8.47	
23			313	244			7.81	

[1]Terr. Mag., **43**, 169-171, 257-260, and 467-470 (1938); **44**, 85-88, 195-198, 321-325, and 395-399 (1939); **45**, 49-52, 155-158, and 477-483 (1940); **46**, 83-86, and 231-237 (1941).

TABLE 1—*Mean hourly values of ionospheric data, Huancayo Magnetic Observatory, April to June, 1941—Continued*

75° west mean time	$h^{max}_{F_1}$	$h^{min}_{F_1}$	$h^{max}_{F_2}$	$h^{min}_{F_2}$	f^o_E	$f^o_{F_1}$	$f^o_{F_2}$	f_{min}
h	*km*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
				May, 1941				
00			302	242			5.50	
01			297	245			5.00	
02			305	254			4.55	
03			318	271			3.94	
04			327	290			3.56	
05			329	293	0.84		3.40	0.70
06			321	283	1.27		4.04	0.77
07	285	265	328	266	2.22	4.10	6.62	0.81
08	268	244	369	317	2.68	4.56	8.10	0.95
09	250	233	411	338	3.03	4.71	8.83	1.18
10	239	230	450	368	3.27	4.78	8.36	1.17
11	232	224	459	390	3.51	4.73	7.94	1.27
12	231	223	463	398	3.57	4.75	7.60	1.33
13	227	224	466	397	3.52	4.69	7.50	1.25
14	233	223	453	386	3.32	4.70	7.62	1.21
15	253	220	432	356	2.93	4.67	8.04	1.17
16	281	245	427	328	2.59	4.47	8.27	1.01
17			411	275	2.02		8.20	0.87
18			426	295	0.95		7.84	0.69
19			444	307	0.85		7.35	0.64
20			400	288			7.35	
21			348	258			7.35	
22			320	240			6.73	
23			305	238			5.87	
				June, 1941				
00			291	236			4.82	
01			294	244			4.55	
02			300	252			4.49	
03			300	259			4.09	
04			299	260			3.75	
05			299	267	0.66		3.37	0.63
06			314	270	1.18		3.49	0.68
07		250	312	244	2.23		5.82	0.77
08	249	220	357	311	2.73	4.53	7.22	1.04
09	230	214	386	328	2.96	4.60	7.38	1.18
10	218	209	409	363	3.24	4.68	7.19	1.21
11	210	203	426	378	3.44	4.70	7.12	1.30
12	211	206	429	389	3.51	4.70	7.13	1.32
13	212	208	435	387	3.43	4.66	7.32	1.28
14	221	212	424	369	3.26	4.59	7.40	1.17
15	230	212	416	343	2.89	4.50	7.53	1.10
16	252	222	396	296	2.54	4.37	7.75	0.95
17			380	251	2.02		7.80	0.74
18			378	275	0.98		7.46	0.64
19			394	288	0.79		6.80	0.59
20			372	276			6.63	
21			334	248			6.80	
22			304	234			6.20	
23			290	230			5.31	

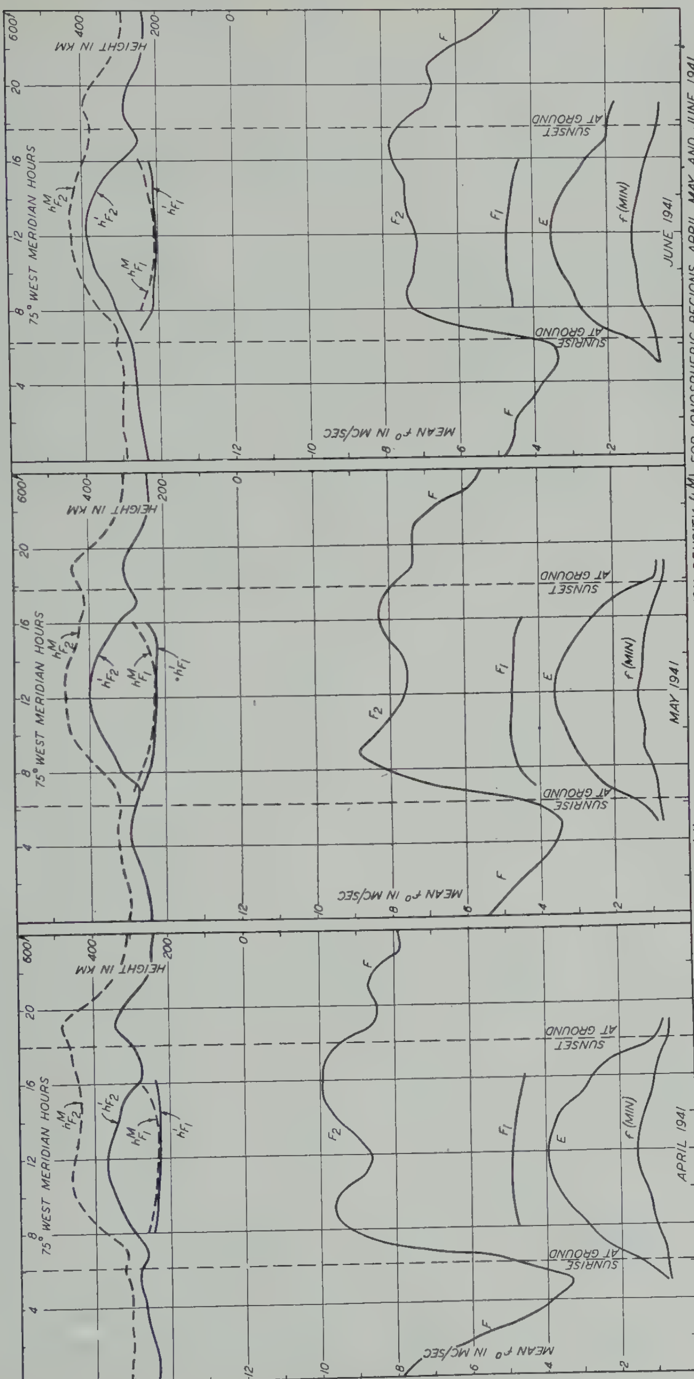


FIG. 1—MEAN CRITICAL FREQUENCY (f^0), MINIMUM VIRTUAL HEIGHT (h'), AND HEIGHT OF MAXIMUM ION-DENSITY (h^M), FOR IONOSPHERIC REGIONS, APRIL, MAY, AND JUNE, 1941, HUANCAYO, PERU

lower regions[2], and the minimum virtual height (h^{min}) for both the F_1- and F_2-regions, the penetration-frequencies for the E-, F_1-, and F_2-regions, and the lowest frequency at which echoes were observed when that frequency was greater than 0.516 Mc/sec.

Figure 1 gives the data in graphical form; the values of h^{min} lie along the continuous line while those of h^{max} are indicated by the broken line.

The 75° west meridian standard times of sunrise and sunset at the Earth's surface for the middle of each month are shown by the broken vertical lines.

Table 2 gives root-mean-square values of F_2-region penetration-frequencies. Since ionization is proportional to the square of frequency, these data are more representative of *average ionization* than the normally used means of penetration-frequencies. The difference between the root-mean-square values of Table 2 and the arithmetical-mean values of Table 1 is an approximate measure of the scatter in individual observations during the month for that particular hour. Root-mean-square values for the E-region, F_1-region, and minimum frequency received have been discontinued because of the absence of appreciable differences between the root-mean-square and arithmetical-mean values.

TABLE 2—*Root-mean-square values of F_2-region penetration-frequencies ($f^0{}_{F_2}$), Huancayo Magnetic Observatory, April to June, 1941*

75° west mean time	Apr.	May	June	75° west mean time	Apr.	May	June
h	*Mc/sec*	*Mc/sec*	*Mc/sec*	*h*	*Mc/sec*	*Mc/sec*	*Mc/sec*
00	7.99	5.62	4.87	12	8.67	7.66	7.14
01	7.51	5.14	4.65	13	9.07	7.51	7.33
02	6.13	4.68	4.62	14	9.59	7.63	7.42
03	4.80	4.07	4.20	15	9.92	8.06	7.55
04	4.30	3.71	3.91	16	9.95	8.29	7.77
05	3.48	3.56	3.48	17	9.88	8.24	7.83
06	4.66	4.11	3.52	18	9.49	7.87	7.48
07	7.65	6.64	5.84	19	8.58	7.39	6.84
08	9.25	8.12	7.29	20	8.51	7.40	6.70
09	9.67	8.86	7.40	21	8.74	7.42	6.88
10	9.52	8.42	7.20	22	8.54	6.81	6.24
11	8.85	7.98	7.14	23	7.99	5.94	5.36

HUANCAYO MAGNETIC OBSERVATORY,
Huancayo, Peru, July 20, 1941

[2]Phys. Rev., 57, 87-94 (1940).

IN MEMORIAM DOCTOR GARMT VAN DIJK, 1877-1940

By H. G. Cannegieter

In the last days of the year 1940 the Netherlands Meteorological Institute has suffered a sad bereavement in the death of the member of its scientific staff, Dr. G. van Dijk. After a short illness he died suddenly and quite unexpectedly in the night of December 19, 1940, at the age of 63 years. Thirty-four years of a busy life had been devoted to the organization and direction of the Magnetic and Seismological Section of the De Bilt Meteorological Institute.

Van Dijk was born June 22, 1877. He studied at the University of Groningen and was given the degree of Doctor of Physics March 4, 1905. On February 1, 1907, he was appointed by the Institute at De Bilt as Assistant Director in charge of the Section of Magnetism and Seismology. After his plans new pavilions were constructed for the magnetic and seismological instruments. The seismological pavilion was finished in 1911 and the magnetic pavilion in 1913.

In 1924 van Dijk was promoted to Director of his Section. He took an interesting and active part in the international work organized by the International Meteorological Organization and, after the institution of the International Union of Geodesy and Geophysics, in the work of the Associations for Magnetism and Seismology. For a long series of years he was the editor of the publications (1) "Caractère magnétique de chaque jour," a work which he continued during the war of 1914-1918, and later of (2) "Caractère magnétique numérique des jours."

In the latest years of his activity he had to devote his attention to the establishment of a new magnetic station in a remote part of the land in a region undisturbed by the difficulties caused by the introduction of electric traction on the railways in our country. As the electrification extended to our Province and the town of Utrecht, a transfer of the magnetic station from De Bilt was necessary. A suitable location was found in Witteveen in the Province of Drente in the northeastern part of the Netherlands. The new station was built after his plans in 1937 and 1938, and continuous registrations started there in July, 1938.

One of the fields of the scientific activity of van Dijk was the preparation of the contribution of the Netherlands to the International Polar Year 1932-1933 for the magnetic station at Angmagssalik in Greenland. With the utmost care he made all preparations for the instrumental equipment of the Station with the necessary magnetic instruments and instructed the four young men who were charged with the responsible task to establish the Station in the foreign country and to maintain for a year the observations in the severe polar climate. After the return of the Expedition van Dijk himself undertook the work of reducing the results and of preparing the material for publication.

Van Dijk was a member of the International Commissions for Terrestrial Magnetism and Atmospheric Electricity and for the International

Polar Year 1932-1933 of the International Meteorological Organization. He represented our country at the triennial assemblies of the International Union of Geodesy and Geophysics for the first time at Prague in 1927 and for the last time at Washington in September, 1939.

It was a great satisfaction to van Dijk, that his work for international organization and science was highly appreciated in foreign countries.

His sudden death, following an apparently minor complication after a slight operation November 30, 1940, ended an active life devoted to our Netherlands Meteorological Institute and to international science.

De Bilt, Netherlands, May, 1941

LETTERS TO EDITOR

(See also page 312)

RESULTS OF MAGNETIC OBSERVATIONS IN MEXICO, MAY, 1941

Table 1 gives the results obtained by Sr. A. Vaca Alatorre at secular-variation stations Oaxaca and Puebla and at a new station Tehuacán. The instrument used was magnetometer-inductor 107 (C. I. W. type) and the values are corrected to international magnetic standards.

TABLE 1

Station	Latitude, north	Longitude, east	Date	Local mean time		Declination, east	Inclination, north	Horizontal intensity
	° ′	° ′	1941	h	h	° ′	° ′	γ
Puebla	19 02.5	261 48.8	May 29	15.3	16.6	9 34.2	.. ....	.....
(el. 2175 m),				15.9	....	.. ....	.. ....	31057
exact re-				16.9	....	.. ....	46 24.4	.....
occupation			30	8.7	9.7	9 35.2	.. ....	.....
				8.4	....	.. ....	46 24.3	.....
				9.1	....	.. ....	.. ....	31036
Tehuacán	18 27.8	262 36.7	May 28	10.9	....	9 28.0	.. ....	.....
(el. 1676 m),				16.2	17.5	9 35.0	.. ....	.....
new station[a]				9.5	15.9	.. ....	45 53.6	.....
				10.4	16.9	.. ....	.. ....	31076
Oaxaca	17 05.0	263 17.3	May 23	10.7	12.1	9 18.4	.. ....	.....
(el. 1550 m),				10.1	16.1	.. ....	44 01.4	.....
exact re-			24	8.7	10.3	9 18.4	.. ....	.....
occupation				8.4	15.9	.. ....	44 03.3[b]	.....
				9.6	....	.. ....	.. ....	31385
			25	9.4	10.9	9 16.9	.. ....	.....
				9.1	....	.. ....	44 01.2	.....
				10.2	....	.. ....	.. ....	31423

[a]In an open field, 1.5 km west of Avenida Nacional and 500 meters south of highway to Puebla; cross in tower of a church is in true azimuth south 154° 19′.9 west.
[b]Value at $15^h.9$ questioned by observer as it is high, namely 44° 04′.7.

OBSERVATORIO ASTRONOMICO NACIONAL,
SECCIÓN MAGNÉTICA,
Tacubaya, Mexico

JOAQUÍN GALLO

CRITICAL FREQUENCIES AND VIRTUAL HEIGHTS OF THE IONOSPHERE, OBSERVED BY THE NATIONAL BUREAU OF STANDARDS AT WASHINGTON, D. C., APRIL TO JUNE, 1941[1]

The following ionosphere data are in continuation of those published in each issue of the JOURNAL since 1936.

The data given in Table 1 are similar to, but not the same as, those published in the form of graphs by the National Bureau of Standards

[1]Report prepared by N. Smith and T. R. Gilliland.

TABLE 1—*Average virtual heights and critical frequencies, National Bureau of Standards, Washington, D. C.*
(Averages for all days of the month, including disturbed days)

EST	h_E	h_{F_1}	h_{F_2}	$f^o{}_E$	$f^o{}_{F_1}$	$f^o{}_{F_2}$	h_E	h_{F_1}	h_{F_2}	$f^o{}_E$	$f^o{}_{F_1}$	$f^o{}_{F_2}$	h_E	h_{F_1}	h_{F_2}	$f^o{}_E$	$f^o{}_{F_1}$	$f^o{}_{F_2}$
h	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*km*	*km*	*km*	*Mc/sec*	*Mc/sec*	*Mc/sec*
	April, 1941						*May, 1941*						*June, 1941*					
00			316			3.54			325			3.72			298			4.36
01			319			3.34			334			3.33			298			3.87
02			319			3.03			337			3.08			309			3.44
03			321			2.76			328			2.81			317			3.07
04			322			2.48			336			2.56			322			2.62
05			332			2.57			314			3.21			291	1.72*		3.50
06		290*	257	1.86	3.2*	3.86		265*	273	2.12	3.4*	4.18	130*	240	310	2.31	3.65	4.27
07	124*	236	276	2.42	3.65	4.73	127*	230	352	2.61	3.88	4.66	124	229	373	2.74	3.99	4.87
08	128	225	318	2.75	3.9	5.15	126	223	384	2.94	4.17	4.96	124	230	361	3.09	4.23	5.22
09	120	210	340	3.03	4.24	5.29	127	227	403	3.16	4.30	5.13	122	222	358	3.27	4.41	5.56
10	118	206	379	3.22	4.38	5.63	123	225	394	3.34	4.44	5.16	121	217	356	3.45	4.49	5.71
11	118	213	359	3.30	4.47	6.04	124	216	406	3.45	4.47	5.42	122	216	401	3.55	4.54	5.66
12	120	209	369	3.35	4.48	6.20	122	222	414	3.48	4.50	5.31	121	218	389	3.59	4.56	5.67
13	119	220	346	3.33	4.48	6.58	126	228	408	3.47	4.52	5.71	123	215	403	3.55	4.57	5.77
14	120	225	334	3.26	4.43	6.64	122	230	372	3.39	4.47	5.85	124	225	386	3.46	4.52	5.76
15	120	222	321	3.16	4.36	6.60	127	233	362	3.25	4.35	5.86	125	224	370	3.32	4.43	5.88
16	127	228	310	2.91	4.07	6.42	130	237	349	3.04	4.20	5.94	126	226	351	3.12	4.26	6.08
17	134	239	287	2.53	3.72	6.48	128*	238	322	2.67	3.91	6.16	126	236	319	2.83	4.04	6.36
18	130*		260	1.98		6.76	125*	250*	291	2.24	3.5*	6.30	124*	240	297	2.40	3.62	6.57
19			246	1.44*		6.71			268			6.35			269			6.60
20			253			5.99			269			6.06			267			6.38
21			260			5.05			278			5.22			274			5.76
22			280			4.30			295			4.49			281			5.24
23			308			3.83			307			4.13			290			4.37

* = Less than ten days.

each month in *Proceedings of the Institute of Radio Engineers.* The averages given there are for undisturbed days while those given here (Table 1) are for all days of the month. The midnight and noon values given for each day in Table 2 are equivalent to the Bureau's values given in code-form in the weekly Ursigrams issued by Science Service.

The data on critical frequencies give implicitly the maximum ionization-densities of the ionosphere layers. The equivalent electron-density in electrons per cubic centimeter is 0.0124 times the square of the critical frequency in kilocycles per second.

2—*Midnight and noon critical frequencies for each day, National Bureau of Standards, Washington, D. C.*

00 EST	12 EST			00 EST	12 EST			00 EST	12 EST		
$f^o{}_F$	$f^o{}_{F_2}$	$f^o{}_{F_1}$	$f^o{}_E$	$f^o{}_F$	$f^o{}_{F_2}$	$f^o{}_{F_1}$	$f^o{}_E$	$f^o{}_F$	$f^o{}_{F_2}$	$f^o{}_{F_1}$	$f^o{}_E$
Mc/sec	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*	*Mc/sec*
	April, 1941				*May, 1941*				*June, 1941*		
†1.8	†4.4	†4.2	† 3.25	† 3.0	5.6	4.5	(3.4)	4.6	(5.4)	...	3.45
†3.1	†5.9	†4.3	† 3.2	†(2.2)	†(4.8)	†(4.4)	†(3.45)	4.3	5.9	4.5	(3.5)
†3.0	†5.1	†4.2	† 3.3	†(3.3)	† 4.5	† 4.3	† 3.4	4.1	5.9	4.5	3.6
†3.0	†5.4	†4.4	† 3.2	† 2.9	5.6	4.5	(3.45)	4.1	5.9	4.7	(3.55)
†2.7	6.8	4.5	3.3	3.9	5.5	4.5	3.4	3.8	6.3	4.6	(3.55)
4.2	7.8	4.6	3.35	NR	NR	NR	NR	4.0	5.9	4.7	(3.55)
†3.2	†5.8	†4.5	†(3.25)	NR	6.2	4.7	(3.4)	4.6	5.9	4.5	(3.55)
3.3	6.9	4.5	(3.35)	3.4	5.7	4.6	(3.45)	4.5	6.4	4.5	(3.6)
3.7	7.3	4.5	(3.4)	3.5	† 5.1	† 4.6	†(3.4)	4.3	6.8	4.6	(3.65)
†3.3	7.5	4.4	3.3	† 4.7	†(4.6)	† 4.2	†(3.5)	†(5.3)	† 5.7	†4.4	†(3.65)
4.4	6.9	4.6	3.25	† 3.0	5.5	4.4	(3.35)	† 3.6	5.9	4.7	(3.6)
4.3	6.9	4.6	3.35	3.6	6.3	4.7	(3.45)	4.6	† 5.0	†4.6	†(3.6)
4.1	7.5	4.5	3.35	5.0	† 4.8	† 4.3	†(3.45)	† 3.9	†<4.5	†4.5	†(3.5)
4.4	8.0	4.6	3.45	† 3.2	5.5	4.8	(3.45)	† 3.9	† 4.9	†4.5	†(3.55)
4.6	7.3	4.6	3.4	4.5	5.5	4.6	(3.5)	† 4.5	5.5	4.5	(3.5)
5.5	8.2	4.6	(3.35)	3.6	5.8	4.5	(3.55)	4.5	5.8	4.6	(3.55)
4.4	6.1	4.7	(3.4)	† 3.7	†<4.5	† 4.5	†(3.5)	3.8	5.9	4.7	3.6
3.6	6.9	4.8	(3.45)	† 2.5	5.3	4.5	(3.55)	† 4.7	† 5.5	†4.5	†(3.5)
†4.8	†4.7	†4.3	†(3.35)	3.4	5.3	4.5	3.4	† 3.4	NR	NR	(3.45)
NR	NR	NR	NR	3.6	6.0	4.7	(3.65)	NR	† 4.9	†4.3	†(3.65)
NR	NR	NR	NR	4.6	5.9	4.4	(3.65)	† 4.2	5.3	4.3	(3.55)
†3.5	†5.7	†4.7	†(3.45)	† NR	† NR	† NR	† NR	4.2	5.4	4.5	(3.6)
3.3	6.3	4.5	†(3.4)	† NR	†(6.1)	† ...	† NR	4.2	5.5	4.5	(3.65)
†3.0	†<4.2	†4.2	†(3.3)	† NR	6.0	4.6	3.5	4.5	6.5	4.7	3.65
†2.2	†5.5	†4.2	† 3.3	4.3	6.2	4.5	3.6	4.4	5.6	4.6	(3.7)
†3.1	†6.2	†4.6	†(3.4)	4.4	5.3	4.4	(3.55)	5.2	5.6	4.5	(3.6)
†3.4	†5.1	†4.5	†(3.4)	3.5	5.3	4.5	3.5	† 3.5	6.1	4.7	(3.7)
†3.5	†4.9	†4.4	† 3.45	† 3.6	† 5.0	† 4.4	†(3.55)	5.0	6.0	4.6	(3.7)
†2.7	†<5.0	†4.4	†(3.4)	† 4.5	† 4.8	† 4.4	†(3.45)	5.2	5.6	4.7	(3.8)
†3.0	†5.2	†4.4	†(3.4)	3.9	5.3	4.4	3.5	4.7	4.8	4.6	3.6
				4.8	6.3	4.5	(3.55)				

-Ionosphere-storm day. NR =No record.
) =Interpolated value. . . . =Characteristic not on record.

ATIONAL BUREAU OF STANDARDS,
UNITED STATES DEPARTMENT OF COMMERCE,
Washington, D. C.

SOLAR PHENOMENA PRECEDING THE IONOSPHERIC STORM OF MARCH 1, 1941

At the Whitin Observatory at Wellesley College a 60-mm Zeiss refractor has been used in conjunction with the Hale spectrohelioscope to study the visual spectra ($\lambda 4800-\lambda 7000$) of bright chromospheric eruptions. The spectra of 20 eruptions were examined between November, 1940, and June, 1941. In general, they showed the hydrogen lines in bright emission, the helium line, $\lambda 5876$, in absorption, and no change in the intensity of the continuous background of the spectrum. There were two conspicuous exceptions to this pattern.

In the spectra of the eruptions of February 26 and 27, the helium line $\lambda 5876$ appeared in bright emission instead of the usual absorption. Furthermore, on February 27, the singlet line of helium, $\lambda 6678$, was also seen as an emission line. These eruptions were accompanied by the usual simultaneous ionospheric disturbances which are now associated with this type of solar activity. However, it is more interesting to realize that these exceptional eruptions were followed, at intervals of $2^d\,9^h$ and $1^d\,12^h$, respectively, by the unusually severe ionospheric and magnetic storm that began at 23^h, EST, February 28. Many more observations are, of course, needed before one can say whether or not a relationship exists between these severe ionospheric disturbances and solar eruptions showing unusual excitation.

The observational record can be further completed by stating that February 28 was cloudy; March 1 was also overcast, but a brief glimpse of the solar disc at $13^h\,55^m$, EST, showed no bright eruptions.

HELEN W. DODSON
SUZANNE E. A. VAN DIJKE

WHITIN OBSERVATORY, WELLESLEY COLLEGE,
Wellesley, Massachusetts, June, 1941

AMERICAN *URSI* BROADCASTS OF COSMIC DATA, GIVING AMERICAN MAGNETIC CHARACTER-FIGURE, C_A, THREE-HOUR-RANGE INDICES, K, AND MEAN K-INDICES, K_A, FOR APRIL TO JUNE, 1941

Summaries of American *URSI* broadcasts have appeared regularly in this JOURNAL since the issue for December, 1930.

As set forth in this JOURNAL for June, 1937, "The Department of Terrestrial Magnetism and the United States Coast and Geodetic Survey with the cooperation of the United States Army and the United States Navy communication-services and several amateur radio stations have undertaken to supply the American character-figure based upon the reports of the seven American-operated observatories—those of the Department of Terrestrial Magnetism at Huancayo in Peru and at Watheroo in Western Australia, and those of the United States Coast and Geodetic Survey at Cheltenham (Maryland), Honolulu (Hawaii), San Juan (Puerto Rico), Sitka (Alaska), and Tucson (Arizona)." This character-figure is being designated C_A, and its values for the first twelve, the second twelve, and all twenty-four hours of each Greenwich day for April to June, 1941, are given in Table 1.

TABLE 1—*American magnetic character-figure C_A for Greenwich half- and full-days based on reports from Cheltenham, Honolulu, Huancayo, San Juan, Sitka, Tucson, and Watheroo for April to June, 1941*

Day	April			May			June		
	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h	0^h-12^h	12^h-24^h	0^h-24^h
1	0.1	0.1	0.1	0.0	0.2	0.1	0.4	0.0	0.2
2	0.3	0.3	0.3	0.1	0.1	0.1	0.0	0.0	0.0
3	0.6	0.4	0.5	0.1	0.0	0.1	0.1	0.0	0.0
4	0.1	0.0	0.1	0.9	0.0	0.5	0.0	0.1	0.0
5	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0
6	0.3	0.2	0.2	0.3	0.1	0.2	0.1	0.2	0.1
7	0.3	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0
8	0.6	0.5	0.5	0.1	0.5	0.3	0.0	0.0	0.0
9	0.6	0.5	0.5	0.5	0.2	0.4	0.5	0.3	0.4
10	0.6	0.9	0.8	0.4	0.3	0.3	0.6	1.1	0.9
11	0.9	0.5	0.7	0.1	0.0	0.0	1.1	0.5	0.8
12	0.6	0.2	0.4	0.0	0.3	0.1	0.4	0.4	0.4
13	0.1	0.0	0.0	0.4	0.2	0.3	1.0	0.9	0.9
14	0.1	0.0	0.0	0.0	0.1	0.0	0.8	0.4	0.6
15	0.0	0.2	0.1	0.1	0.1	0.1	1.0	0.5	0.8
16	0.6	0.1	0.3	0.4	0.4	0.4	0.0	0.0	0.0
17	0.1	0.3	0.2	1.0	0.4	0.7	0.2	0.9	0.5
18	0.4	0.6	0.5	0.4	0.2	0.3	0.8	0.4	0.6
19	1.0	0.6	0.8	0.0	0.0	0.0	0.1	0.4	0.2
20	0.5	0.4	0.4	0.0	0.0	0.0	0.8	0.5	0.6
21	0.4	0.1	0.2	0.4	0.8	0.6	0.6	0.3	0.4
22	0.1	0.1	0.1	1.1	0.6	0.9	0.4	0.3	0.4
23	0.0	0.0	0.0	0.7	0.7	0.7	0.1	0.0	0.0
24	1.1	1.4	1.2	0.9	0.6	0.7	0.1	0.4	0.2
25	1.1	0.6	0.9	0.6	0.4	0.5	0.0	0.1	0.1
26	0.6	0.1	0.4	0.4	0.2	0.3	0.1	0.6	0.3
27	0.0	0.0	0.0	0.1	0.1	0.1	0.7	0.4	0.6
28	0.4	0.8	0.6	0.2	0.2	0.2	0.1	0.1	0.1
29	0.8	0.0	0.4	0.6	0.0	0.3	0.4	0.2	0.3
30	0.0	0.0	0.0	0.1	0.4	0.2	0.0	0.1	0.1
31				0.5	0.4	0.5			
Means	0.4	0.3	0.4	0.3	0.2	0.3	0.3	0.3	0.3

Since April 6, 1940, American *URSI* broadcasts have given three-hour-range indices, K, for each of the seven American-operated observatories. The eight indices for each day give geomagnetic activity for three-hour periods successively during the Greenwich day. The indices range from "zero" very quiet to "nine" extremely disturbed. The K-indices for Sitka (Si), Cheltenham (Ch), Tucson (Tu), San Juan (SJ), Honolulu (Ho), Huancayo (Hu), and Watheroo (Wa), for April to June, 1941, are given in Table 2. Interpolated indices are shown thus: $\dot{3}$.

In the manner set forth in the JOURNAL for September, 1940, the indices are standardized into reduced indices K_r to eliminate local variations. A weighted mean index, K_A, is derived from the reduced indices. The reduced indices from Si, Ch, and Wa are given double weight and

Table 2--Three-hour-range indices, K, April to June 1941

April 1941

	1	2	3	4	5	6	7	8
Si	0002 1102	1132 4112	2422 2311	2223 1001	0112 1111	0411 2121	0014 3222	2012 3122
Ch	3301 2113	4231 2222	5522 2233	3232 0012	1331 1112	3422 0123	1223 2234	3222 2124
Tu	1101 1113	3231 2222	3412 3331	2231 2102	1220 1101	2411 1112	0123 3233	4112 2213
SJ	1200 1122	3231 1122	3411 1231	2220 1011	1120 0012	3322 4232	0131 3244	4221 3013
Ho	0212 1021	1232 3112	3323 2312	1122 1001	0221 1001	1121 3011	0134 3233	3112 2112
Hu	2102 3322	3122 3322	3311 3432	2121 1211	1110 2322	3311 1322	1122 4442	3211 2332
Wa	1112 2311	2112 4223	2212 3442	2222 1111	1111 1112	2211 3212	1112 2133	3211 2232
	9	10	11	12	13	14	15	16
Si	2433 3221	1253 2433	3455 2222	3633 3221	1022 1000	0231 1000	0001 1112	3105 4111
Ch	3432 3222	2452 2435	4454 2333	4543 2222	4221 1122	2221 0010	0111 2124	4224 3211
Tu	3333 2322	2353 3435	3455 2232	2543 3212	3221 1011	1220 1000	0102 2223	4224 3001
SJ	3323 2121	1242 2335	3333 2131	3433 2012	3110 0001	1220 0000	0002 2223	4223 3101
Ho	2333 2232	1233 2334	2344 2121	1433 3121	2012 1000	0001 1010	0121 2223	3324 3012
Hu	2221 3431	1221 3454	2331 3432	3322 3222	2110 1111	1220 2110	0101 3333	4212 3221
Wa	2332 3311	2142 1434	3234 3322	2233 2211	2112 2211	1111 1000	0001 0012	3114 4111
	17	18	19	20	21	22	23	24
Si	1023 2212	3231 4133	2775 3322	2141 2122	3222 3121	0330 1111	1002 2010	0167 7544
Ch	1322 3322	4222 4234	3664 3333	4241 3234	4322 2232	0331 1223	1101 2022	1246 6555
Tu	1122 2223	4222 3125	3654 2322	3232 2323	2321 1121	1330 1122	1101 1012	0256 5644
SJ	1111 2322	3212 3125	2553 3223	3233 2112	3212 1122	0332 2111	0002 2011	1245 5554
Ho	1122 2213	3111 2025	2453 4222	1123 1112	2232 1121	0221 1112	0101 2211	1245 5442
Hu	1121 3421	3203 3244	2342 3442	3222 4322	2211 3221	1320 3322	1101 2111	1245 6653
Wa	2122 2213	3221 2324	1343 4232	2231 1122	2221 3120	1110 0112	0102 2001	1145 5654
	25	26	27	28	29	30		
Si	4765 2222	2535 1111	1032 0000	2223 3233	4331 0000	0110 0000		
Ch	6554 2433	4435 2123	3121 0112	2323 2244	5332 1001	2211 0111		
Tu	5554 3323	3435 1211	1121 0001	2331 2233	5430 0001	0210 0100		
SJ	5433 1323	4324 2112	2010 1000	2422 2243	4331 0001	1211 0000		
Ho	3554 2312	2324 0101	0012 0020	0322 3333	5412 0001	1221 0012		
Hu	5422 3432	3322 3322	2120 0211	2323 3443	3320 0001	1211 1200		
Wa	3353 2333	2324 2112	2211 1111	1122 3344	5432 0000	1211 0000		

May 1941

	1	2	3	4	5	6	7	8
Si	0001 2112	1321 1101	1332 0011	1355 2100	2032 1110	0233 3020	0320 0200	0003 2122
Ch	0002 2333	2321 2122	2330 1121	1453 2122	3123 1211	1234 2131	2320 0221	0113 2233
Tu	0002 2122	1220 1211	1321 1121	1443 2212	3123 2120	1333 2121	0320 2111	0003 2233
SJ	0002 0213	2220 0022	2220 0011	1443 3212	2112 2200	0224 1020	3311 2220	0103 3243
Ho	0101 1110	1221 1120	0212 0010	0453 1111	1031 2120	2132 2120	2231 0110	0013 3132
Hu	0002 3422	2220 3321	2221 2221	2433 2321	2111 3221	1122 3231	2320 1220	0012 3332
Wa	0101 3243	0111 1212	0111 1211	0333 2211	1121 2100	1113 3110	0120 0011	0013 2132
	9	10	11	12	13	14	15	16
Si	3333 2112	3232 2211	2113 2000	1300 0122	2221 2210	0002 1211	3112 0122	3143 3312
Ch	3443 1133	4322 2223	3112 2122	2312 1133	3333 2322	1212 1224	3222 0233	4333 4323
Tu	3332 1223	3222 2222	3111 1002	2311 1033	4332 2211	1211 1213	3112 1122	4243 2332
SJ	3332 0222	3321 2232	2112 1001	1311 2022	3322 2211	1111 0113	3111 0122	3232 3311
Ho	3232 2122	3211 1112	2112 2000	1022 1022	2122 1121	1200 1123	2211 0111	3132 2222
Hu	3221 1222	3311 2322	2111 1111	1301 2122	3323 3311	1111 2311	1111 2221	3132 4421
Wa	2111 3111	3111 1211	2102 1000	1211 1111	2222 2110	1102 1101	2111 0101	2134 4300
	17	18	19	20	21	22	23	24
Si	1577 6222	2311 0121	2201 0000	0000 0102	2122 0333	4525 5223	2354 5224	3344 3231
Ch	2564 3223	2412 1233	3211 0121	1001 1223	3233 1355	5534 3344	3344 3345	3353 3243
Tu	1665 3222	2421 1122	3310 0000	0101 1202	2132 2353	5524 3342	3354 3234	3332 2133
SJ	1443 3111	2312 0232	3201 1020	0001 2101	2322 1345	5324 2144	2235 4233	3433 1232
Ho	1555 3232	1322 1122	1110 0010	0002 1201	3233 2343	3334 2141	2143 3234	3333 2132
Hu	1333 3221	2311 2322	2211 2121	0012 2212	2322 2451	4323 4443	2233 4333	3332 3332
Wa	0445 4211	0311 1112	1210 0000	0001 1101	1221 1233	4433 4223	1233 4234	2333 3232
	25	26	27	28	29	30	31	
Si	3343 3323	3232 2111	2223 1010	2232 3112	3332 1012	3101 1221	3122 2122	
Ch	5323 2234	3233 2133	3232 2123	2242 1224	3442 1223	3111 2233	4332 2232	
Tu	4323 1213	2132 2111	2222 1101	1222 3113	3342 2111	3112 2322	4422 3232	
SJ	4213 1023	3132 1131	2210 0211	2121 1223	2331 0101	3101 2322	4322 2431	
Ho	2322 1213	2323 2121	1223 1133	0233 2123	1333 2021	3122 2322	3312 2111	
Hu	4312 3323	3122 3321	2211 2321	1121 2322	2231 3221	3101 4332	4321 2321	
Wa	2332 3222	2222 3222	1111 1121	1112 2211	1331 1211	2111 2211	3211 2241	

Table 2--Three-hour-range indices, K, April to June 1941--concluded

June 1941

	1	2	3	4	5	6	7	8
Si	2231 1010	2100 0000	1012 1000	0100 0000	1021 0111	1203 2121	1020 1000	0021 1100
Ch	3442 1122	2210 0101	2022 1111	1211 0322	2222 1222	2113 2222	2122 2101	0122 1211
Tu	3341 1211	2110 1100	2022 2111	0110 0111	1121 2112	2113 2222	2130 2201	0132 2313
SJ	2331 1001	1002 0101	2023 1121	1103 0301	2220 0110	2103 1211	1121 0201	0022 1000
Ho	2232 2020	2010 0020	2021 0000	1100 0322	1120 0012	1023 2212	1021 2002	1023 1011
Hu	2231 2221	1010 1210	2111 2220	1101 1431	1111 2321	2112 3321	1020 2211	1012 2321
Wa	1220 1101	2101 0000	2112 0100	1210 0001	1011 0120	1113 2211	1011 2100	0121 1100

	9	10	11	12	13	14	15	16
Si	0003 2112	3245 5423	5432 1232	2430 3221	0378 7225	4351 3112	2565 4221	0120 1000
Ch	2214 3224	3244 5535	6443 2343	3433 3332	1456 4334	5442 2134	4554 3233	1221 1112
Tu	3125 3334	2343 5535	6453 2332	2431 3423	2465 4433	4531 2234	3354 3223	1131 1212
SJ	0114 3113	3234 4434	4343 1342	2320 1210	0445 3423	4522 2223	2334 2233	0120 0210
Ho	0224 2122	1344 5434	5333 2443	2230 3100	1455 4333	4342 2123	3243 3132	2020 0010
Hu	0113 3322	3221 5533	4332 2431	2320 3331	1333 4433	3321 3232	2334 4332	0111 1110
Wa	0214 2112	1233 5323	4332 1221	1221 2221	1456 3334	4231 3112	1254 3221	1110 1111

	17	18	19	20	21	22	23	24
Si	1234 3343	3421 0120	0102 1222	4464 3222	3334 2111	1234 1121	2110 1111	1113 2112
Ch	2233 2353	4432 1332	1122 2234	3453 2334	3342 2232	2133 2233	2211 1223	1113 2234
Tu	2243 3454	4433 3333	2113 2333	3463 2224	3333 2232	2234 1322	2212 2232	2123 2233
SJ	1213 1353	5333 3330	0010 1223	2353 1223	3232 2022	1033 2111	1101 2211	1012 1122
Ho	1233 3343	3332 3212	1211 2332	2344 1122	3223 1111	0133 1022	1101 0021	1013 2133
Hu	1122 3463	5332 3431	1111 2322	2341 3331	3221 3331	1132 3231	1100 2211	1011 3322
Wa	0123 2134	3221 1120	0000 2212	2343 3322	3332 2221	2233 1122	1111 1211	1112 3233

	25	26	27	28	29	30
Si	2100 1012	2201 1123	2442 2110	2023 1111	2221 1010	1112 1002
Ch	2111 1123	4221 1245	3453 2232	3123 2232	3233 2232	1212 2223
Tu	3111 1123	3222 1134	3553 2132	3133 2312	3343 2222	2322 2122
SJ	2001 2113	3102 0033	2333 2132	2122 0122	3232 2111	1201 2012
Ho	2111 1022	1022 1133	2343 3121	1122 2022	3333 2020	0122 1022
Hu	2111 3221	3101 2233	2333 2321	2121 2322	3233 3321	1211 3212
Wa	2100 1022	3111 2223	2332 3111	2112 2121	2132 1121	1111 1111

**Interpolated

Table 3--Weighted average of reduced three-hour-range indices, April to June 1941

Day	April 1941		May 1941		June 1941	
	Values K_A	Sum	Values K_A	Sum	Values K_A	Sum
1	1 1^x 0^x 1^x 2 1^x 1 2	11	0 0^x 0 1^x 2 2 2 2^x	10^x	2 2^x 3 1 1 0^x 1 1	12
2	2^x 1^x 2^x 1^x 3 2 1^x 2^x	17	1 2 2 1 1^x 1^x 1^x 1^x	12	2 1 0^x 0^x 0 0^x 0^x 0	5
3	3 3^x 1^x 2 2^x 3 2^x 2	20	1 2 2 1 0^x 1 1^x 1	10	2 0^x 1^x 2 1 0^x 0^x 0^x	8^x
4	2 2 2^x 1^x 1 0^x 0^x 1^x	11^x	1 3^x 4 3^x 2 1^x 1 1	17^x	1 1^x 0^x 1 0 2 1 1	8
5	0^x 1^x 2 1 1 1 0^x 1^x	9	2 0^x 2 2 1^x 1^x 1 0^x	11	1^x 1 1^x 1 0^x 1 1^x 1	9
6	2 3 1^x 1^x 2 1^x 1^x 2	15	1 1^x 2 3 2^x 1 2 0^x	13^x	1^x 1 1 3 2 2 1^x 1^x	13^x
7	0^x 1 2 3 3 2 3 3	17^x	1 2^x 2 0 0^x 1^x 1 0^x	9	1^x 0^x 2 1 1^x 1 0 0^x	8
8	3 1^x 1^x 1^x 2^x 1^x 2 2^x	16	0 0^x 0^x 3 2 1^x 3 2^x	13	0^x 0^x 2 2 1 1^x 0^x 0^x	8^x
9	2^x 3 3 2^x 3 2^x 2 1^x	20	3 2^x 2^x 2 1^x 1^x 2 2	17	0^x 1^x 1 4 2^x 1^x 1^x 2^x	15
10	1^x 2^x 4 2 2 4 3 4^x	23^x	3 2 1^x 1^x 1^x 2 1^x 1^x	14^x	2^x 2 3^x 3^x 5 4^x 2^x 3^x	27
11	3 3 4 4 2^x 2^x 2^x 2	23^x	2^x 1 1 2 1^x 0 0^x 0^x	9	5 3 3^x 2^x 1^x 3 3^x 2	24
12	3 4 3 3 2^x 2 1^x 1^x	20^x	1^x 2 1 1^x 1 0^x 2 2	11^x	2 3 2^x 1 2^x 2^x 2 1	16^x
13	2^x 1 1^x 1^x 1 0^x 0^x 1	9^x	2^x 2 2 2^x 2 2 1^x 0^x	15	1 3^x 5 5^x 4 3 2^x 3^x	28
14	1 2 2 1 1 0 0 0	7	1 1 0^x 1^x 1 1^x 1 2	9^x	4 3 3 1^x 2^x 1^x 2 2^x	20
15	0 0^x 0^x 1^x 1^x 1^x 1^x 3	10	2^x 1^x 1^x 1^x 0^x 1^x 1^x 1^x	12	2^x 3 4^x 4 3 2 2^x 2	23^x
16	3^x 2 1^x 4 3^x 1 0^x 1	17	3 1^x 3 3 3 3 1^x 1^x	19^x	1 1 2 0^x 1 1 0^x 0^x	7^x
17	1^x 1 2 2 2^x 2^x 1^x 2^x	15^x	1 4 5 4^x 3^x 2 2 1^x	23^x	1 1^x 2^x 3 2^x 3 4^x 3	21
18	3^x 2 2 1^x 3 1^x 2^x 4^x	20^x	1^x 3 1 1^x 1 1^x 2 2	13^x	3^x 3 2^x 2 1^x 2^x 2^x 1	18^x
19	2 4^x 5 3^x 3 3 2^x 2^x	26	2 2 1 0^x 0^x 0 1 0^x	7^x	0^x 1 1 1^x 1^x 2^x 2 2^x	12^x
20	2^x 2 3 2 2^x 2 2 2^x	18^x	0 0 0 1 1 1^x 0^x 1^x	5^x	2^x 3 4^x 3 2 2^x 2^x 2^x	22^x
21	3 2^x 2 1^x 2^x 1^x 2 1	16	2 2 2^x 2^x 1 3 4 3^x	20^x	3 2^x 3 2^x 2 1^x 2 1^x	18
22	0^x 2^x 2^x 0^x 1 1^x 1 2	11^x	4 4 2^x 4 3^x 2^x 3 3	26^x	1^x 1 3 3 2 1^x 2^x 1^x	16
23	0^x 1 0 1^x 2 0^x 1 1	7^x	2 2 3^x 3^x 3^x 2^x 3 4	24	1^x 1 0^x 1 1^x 1^x 1^x 1^x	10
24	1 2 4 5^x 5^x 5^x 4^x 4	32	3 3 3^x 3 2^x 2 3^x 2	22^x	1^x 0^x 1 2^x 2 2 2^x 2^x	14^x
25	4^x 4^x 4^x 3^x 2^x 3^x 2 3	28	3^x 2^x 2 2^x 2 2 2 3	19^x	2 1 0^x 1 1^x 1^x 2 2	11^x
26	3 3^x 2^x 4 2 1^x 1 2	19^x	2^x 1^x 2^x 2^x 2 1^x 2 1^x	16	3 1 1 1^x 1 1^x 3 3^x	15^x
27	1^x 1 2 1 0^x 0^x 0^x 0^x	7^x	2 1^x 1^x 2 1 1 1^x 1^x	12	2^x 3 3^x 3 2 1^x 2 1	18^x
28	1^x 2^x 2^x 2^x 2^x 2^x 3^x 3^x	21	1^x 1^x 2^x 2 2 1^x 1^x 2^x	15	2 1 2 2^x 1^x 1^x 2 1^x	14
29	4^x 3^x 3 1^x 0 0 0 0^x	13	2 3 3 2 1^x 1 1^x 1^x	15^x	2^x 2 3 2^x 1^x 1 2 1	15^x
30	1 2 1 1 0 0^x 0 0^x	6	3 1 0^x 1^x 2 2^x 2 1^x	14	1 1^x 1 2 1^x 1 1 2	11
31			3^x 2^x 2 2 2 2 2^x 1^x	18		

those from Tu, SJ, Ho, and Hu are given single weight. The weighted indices, K_A, for April to June, 1941, are given in Table 3. A superior cross ($^{\times}$) following an index-number denotes a half-unit, thus $5^{\times}=5.5$, etc.

H. F. Johnston

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C., July 20, 1941

CAPE TOWN MAGNETIC DATA

The reduction and analysis of all data collected at the Magnetic Observatory, Cape Town, during the years 1933-40 have been completed with the exception of certain details with regard to the last six months of 1940, such as the international quiet and disturbed days which have not yet been announced.

The publication of the observations during the first four years was delayed by the printer and it is impossible, at the present time, owing to the existing war conditions, to proceed with their publication.

A summary of the mean annual values of the magnetic elements for the Magnetic Observatory, Cape Town, are given below:

Magnetic Observatory, Cape Town, Mean Yearly Values, 1933-40

Year	Declination, west		Horizontal intensity	Vertical intensity	Inclination		North intensity	West intensity	Total intens
	°	′	γ	γ	°	′	γ	γ	γ
1933	24	39.9	15050	−29733	−63	09.2	13677	6281	3332
1934	24	36.7	14955	−29667	−63	14.9	13596	6228	3322
1935	24	34.5	14857	−29608	−63	21.2	13511	6179	3312
1936	24	31.2	14765	−29525	−63	25.9	13434	6128	3301
1937	24	28.2	14674	−29455	−63	31.1	13356	6079	3290
1938	24	24.4	14585	−29361	−63	35.0	13281	6026	3278
1939	24	19.8	14509	−29254	−63	37.2	13220	5980	3265
1940	24	16.0	14433	−29164	−63	40.2	13158	5932	3254

A. Ogg

Magnetic Observatory,
Hermanus, Cape Province, South Africa, July 8, 1941

SOLAR AND MAGNETIC DATA, APRIL TO JUNE, 1941, MOUNT WILSON OBSERVATORY

The magnetic storm of May 21, 1941, ended a sequence of four which began with the great storm of March 1. Each storm of this sequence was apparently associated with a different sunspot group: That of March 1 with Mount Wilson No. 7132, 24° west, 16° north at the beginning of the storm; March 28 with No. 7156, 13° east, 8° north; April 24 with No. 7172, 7° east, 6° south; May 21 with No. 7192, 0°, 16° south. These storms, however, may have been associated with other less active groups or with hypothetical activity in the region of No. 7132, although no spot or other activity was seen in that region after it passed from view at the west limb on March 4.

Day	April 1941						May 1941						June 1941					
	K_2		$H\alpha$	$H\alpha$	No.	Mag'c	K_2		$H\alpha$	$H\alpha$	No.	Mag'c	K_2		$H\alpha$	$H\alpha$	No.	Mag'c
	Whole disk	Central zone	bright	dark	groups	char.	Whole disk	Central zone	bright	dark	groups	char.	Whole disk	Central zone	bright	dark	groups	char.
1	..	..	..	..	..	0	2	2	2	1	4	0	2	1	2	2	3	0.5
2	..	..	..	..	..	0	2	2	2	1	4	0	2	1	2	1	2	0
3	..	..	..	..	..	...	2	2	2	1	4	0	2	2	2	2	4	0
4	..	..	..	..	..	...	2	2	2	1	3	0.5	2	2	3^{d}	1	4^{h}	0
5	2	1	2	1	1	...	2	2	2^{c}	1	3	0	2	2	3	2	5	0
6	2	1	1	1	3	...	2	2	2	1	3^{f}	0.5	2	2	3	1	3	0
7	2	1	2^{d}	1	4	...	2	1	2	1	3	0	..	..	..	..	..	0
8	2	2	2	1	5	0	2	1	2	2	4	0	2	2	3	2	6	0
9	..	..	..	..	5	0	1	1	1	1	4	0.5	2	2	3	2	8^{g}	0.5
10	..	..	..	..	..	...	2	1	2	2	2	0	2	3	3^{c}	3	7	1
11	..	..	..	..	..	...	2	2	2	2	3	0	3	3	3	3	5	0.5
12	..	..	..	..	..	...	1	1	2	2	3	0	3	2	3	3	5^{g}	0.5
13	..	..	..	..	..	...	1	1	1	2	2	0.5	2	2	3	3	4	1
14	..	..	..	..	1	...	1	1	1	2	2	0	3	2	3	3	3	0.5
15	2	2	2	3	1	...	1	1	1	3	2	0	2	2	3	4	4	0.5
16	2	2	2	2	2	...	2	1	2	3	4	0.5	2	2	2	3	2	0
17	2	1	2	2	3	0	2	1	2	2	5	0.5	2	1	2	3	4	0.5
18	2	1	2	2	3	0.5	..	..	..	..	2	0	2	2	2	4	3	0.5
19	2	1	2	3	3	0.5	2	1	2	3	4	0	2	1	2	2	3	0.5
20	1	1	1	2	1	0.5	2	2	2	2	3	0	2	1	2	2	5^{b}	0.5
21	1	1	1^{d}	3	1	0	2	3	2	2	4	0.5	2	2	2	2	4	0.5
22	1	1	2	2	1	0	2	3	2	2	6	1	2	1	3	1	5^{b}	0.5
23	1	2	1	3	3	0	2	2	2	2	4	0.5	2	2	3	1	4	0.5
24	1	2	2	3	3^{e}	1.5	2	2	2	2	4	0.5	2	2	3	1	4	0
25	2	2	2	3	2	1	2	2	3	2	2	0.5	3	3	3	1	6	0
26	2	1	1	3	4	0.5	2	2	2	2	2	0	..	..	..	..	5^{a}	0.5
27	1	1	1	2	4	0	2	2	2	1	3	0	2	3	3^{c}	1	6	0.5
28	2	1	2	2	4	0.5	..	..	..	..	2	0	3	2	4^{c}	2	7	0
29	..	..	..	..	3	0.5	..	..	..	..	1	0.5	3	2	4	2	8	0.5
30	..	..	..	..	..	0	2	2	2	1	2	0	3	3	4^{d}	2	7	0
31							2	1	2	1	3	0.5						
Mean	1.7	1.3	1.7	2.2	2.7	0.3	1.8	1.6	1.9	1.7	3.1	0.2	2.3	2.0	2.8	2.1	4.7	0.3

NOTE—For an explanation of these tables see this JOURNAL, 35, 47-49 (1930).

The character-figures of solar phenomena are estimated from the spectroheliograms which are made with a 2-inch solar image, usually in the early morning. Very bright chromospheric eruptions are reported in these notes if observed at any time during the day.

a, b Formation of a new group which later developed to average size or larger; (a) less than 30° from the center of the disk, (b) more than 30° from the center of the disk.

c, d Very bright chromospheric eruptions; (c) less than 30° from the center of the disk, (d) more than 30° from the center of the disk.

e, f, g, h, i, j, k, l Passage of a large or active group across the central meridian within 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° of the center of the disk, respectively.

Magnetic storms

Greenwich mean time							Range hor. int.
Beginning			Ending				
1941	*h*	*m*	*d*	*h*	*m*		γ
Apr. 24	07	..	26	11	..		165
May 21	16	..	23	24	..		120
June 9	09	12*	11	24	..		100
13	03	42*	14	08	..		130
July 4	18	..	7	12	..		445

*Sudden commencement

Small magnetic disturbances beginning on June 9 and 13, were probably associated with group No. 7201, which crossed the central meridian on June 9.3, 12° north of the center of the disk.

The great magnetic storm which began on July 4, 1941, was probably associated with group No. 7218, which crossed the central meridian on July 3.9, 9° north of the center of the disk. Bright chromospheric eruptions occurred near this group on July 3 from 15^h to 21^h (maximum $16^h\,24^m$), and on July 8 from $14^h\,36^m$ to $14^h\,56^m$, and from $15^h\,36^m$ to $16^h\,28^m$. The storm was preceded on July 3 at $12^h\,17^m$ and on July 4 at $3^h\,22^m$ by sudden increases in the horizontal intensity of the Earth's magnetic field. Within a few hours following these increases the field-strength returned to normal. The storm began at about 18^h on July 4, although the fluctuations were small for about six hours. The greatest variations in the horizontal intensity at Mount Wilson were from 08^h to 16^h on July 5. The total range was 445 gammas from about 45 above normal to 400 below. A brilliant aurora borealis accompanied the magnetic storm and was visible at Mount Wilson from 22^h to 23^h. On July 6 and 7 the horizontal intensity was still below normal and the fluctuations, although numerous, were not large. The field-strength had returned approximately to normal by the end of July 7, 1941.

Seth B. Nicholson
Elizabeth Sternberg Mulders

Carnegie Institution of Washington,
Mount Wilson Observatory,
Pasadena, California

ERDMAGNETISCH RUHIGE UND GESTÖRTE TAGE IM ZWEITEN HALBJAHR 1940

An die Herren Direktoren der erdmagnetischen Observatorien:

Dr. G. van Dijk ist am 19. Dezember 1940 gestorben; H. G. Cannegeiter hat ihm in *Hemel en Dampkring* [**39**, 1-3 (1941)] einen Nachruf gewidmet.

Dr. J. A. Fleming, als Präsident der Internationalen Gesellschaft für Erdmagnetismus und Elektrizität, hat dem Unterzeichneten die vorläufige Fortführung der Internationalen Erdmagnetischen Charakterzahlen übertragen. Im Anschluss an van Dijks "Liste der ruhigen und gestörten Tage für das erste Halbjahr 1940" [abgedruckt Met. Zs., **58**, 33 (1941) und Terr. Mag., **46**, 129 (1941)] folgen hier die fünf ruhigsten und die fünf am meisten gestörten Tage der Monate Juli bis Dezember, 1940.

1940	Ruhig					Gestört				
Juli	2	17	18	20	27	4	10	13	14	30
August	15	16	17	24	30	3	6	9	11	26
September	10	12	17	19	23	1	7	26	27	28
Oktober	13	14	23	24	30	1	7	8	25	26
November	8	10	11	18	19	12	13	22	25	29
Dezember	6	7	8	18	19	20	21	22	30	31

Für diese Auswahl standen zur Verfügung Charakterschätzungen an 44 Observatorien für Juli bis September, an 26 Observatorien für Oktober bis Dezember; ausserdem wurden berücksichtigt die dreistündlichen Kennziffern für Potsdam und Kopenhagen, ferner eine vorläufige Auswahl, die Dr. Fleming auf Grund der amerikanischen Kennziffer vorgeschlagen hatte.

Zur Reproduktion werden vorgeschlagen:

**1940 September 26, 15 Uhr bis September 27, 9 Uhr.

*1940 Juli 13; August 3; Oktober 7 und 8; November 25.

GEOPHYSIKALISCHES INSTITUT,
Potsdam, 1941 Mai 14.

J. BARTELS

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory

April to June, 1941

(Latitude 57° 03′.0 N., longitude 135° 20′.1 or $9^h\,01^m.3$ W. of Gr.)

April 19—A short period of increased activity began gradually at 05^h GMT, April 19. Maximum storminess occurred between 08^h and 09^h with decreased values of all elements. After 09^h conditions slowly returned to normal.

April 24-25—A small magnetic storm began abruptly at $08^h\,39^m$ GMT, April 24. The activity increased gradually until about 15^h and then began a gradual decrease. The disturbance consisted of large bays. After 15^h a short-period vibration was superimposed on the long-period motion. After 08^h, April 25, there was a slow return to normal. Ranges: D, 126′; H, 884 gammas; Z, 804 gammas.

May 17—A small disturbance began gradually at about $04^h\,05^m$ GMT, May 17. The activity increased sharply to a sudden large movement on all traces at $06^h\,22^m$. After 14^h conditions began to return to normal. By 22^h the trace was calm. Ranges: D, 141′; H, 890 gammas; Z, 742 gammas.

June 9-10—A period of moderately disturbed conditions began abruptly at $09^h\,13^m$ GMT, June 9, with a sudden movement on all traces. The disturbance continued with large bays until 21^h, June 10.

June 11-12—A sudden commencement was recorded at $00^h\,14^m$ GMT, June 11. Thereafter the trace was only mildly disturbed until the close of June 12.

June 13-15—A small magnetic storm began abruptly at $03^h\,42^m$ GMT, June 13. After 07^h there occurred a depression in the value of all elements. After 13^h the values of the elements returned to about normal, but continued mildly disturbed until about 20^h, June 15. Ranges: D, 99′; H, 970 gammas; Z, 738 gammas.

Robert E. Gebhardt, *Observer-in-Charge*

Cheltenham Magnetic Observatory

April to June, 1941

(Latitude 38° 44′.0 N., longitude 76° 50′.5 or $5^h\,07^m.4$ W. of Gr.)

April 18-20—A storm began at $19^h\,06^m$ GMT, April 18, and ended April 20 at $09^h\,30^m$. The storm was characterized by long-period oscillations between 04^h and 11^h, April 19. The highest K-number was 6. Ranges: D, 38′; H, 96 gammas; Z, 113 gammas.

April 24-26—A storm began gradually at 06^h GMT, April 24, and ended at 11^h, April 26. This storm is of interest because it occurred on the second 27-day interval after the great storm of March 1, 1941. The

highest K-number was 6. Ranges: D, 40′; H, 150 gammas; Z, 180 gammas.

May 17—A disturbance began at 03^h 28^m GMT, May 17, and ended at midnight of the same day. The highest K-number was 6.

May 21-26—A disturbance began at 17^h 12^m GMT, May 21, and lasted until 08^h, May 26. The highest K-number was 5.

June 9-12—A disturbance began abrubtly at 09^h 12^m GMT, June 9. The field was more or less disturbed until the end of June 12. The highest K-number was 6 which was reached during the first hour of June 11.

June 13-14—A storm began at 03^h 43^m GMT, June 13, and ended June 14 at 09^h. The greatest K-number was 6. Ranges: D, 27′; H, 142 gammas; Z, 156 gammas.

June 14-15—A moderate disturbance took place between 18^h GMT, June 14, and 24^h, June 15. The highest K-number was 5.

Albert K. Ludy, *Observer-in-Charge*

Tucson Magnetic Observatory

April to June, 1941

(Latitude 32° 14′.8 N., longitude 110° 50′.1 or 7^h 23^m.3 W. of Gr.)

April 24-26—A moderate storm began at 07^h 10^m GMT, April 24, with long-period fluctuations. The major activity ended at 10^h, Ap il 25, though small fluctuations continued until 11^h, April 26. Ranges: D, 19′.5; H, 200 gammas.

June 13-14—A moderate storm began abruptly at 03^h 43^m GMT, June 13, with a sudden increase in H of 40 gammas in five minutes, but with only very small initial D- and Z-disturbances. Several long-period and many short-period small fluctuations showed. The principal activity ended at 09^h, June 14. Ranges: D, 17′.3; H, 154 gammas.

J. H. Nelson, *Observer-in-Charge*

Alibag Magnetic Observatory[1]

January to March, 1941

(Latitude 18° 38′.3 N., longitude 72° 52′.3 or 4^h 51^m.5 E. of Gr.)

January 16-17—A moderate disturbance began at about 16^h GMT, January 16, with a gradua commencement. H began to rise very gradually till 22^h, January 16, when the oscillations became more pronounced. The disturbance practically ended at 20^h, January 17, though minor movements continued for some hours. Ranges: D, 7′.1; H, 130 gammas; Z, 41 gammas.

February 13—A moderate disturbance began at about 04^h GMT, February 13. H reached its maximum at 06^h 23^m and thereafter began to fall reaching its minimum at 13^h 25^m. The disturbance practically ended at 22^h.5. Ranges: D, 4′.4; H, 162 gammas; Z, 175 gammas.

March 1—A severe storm began at 03^h 58^m GMT, March 1, with a sudden rise of 1′.4 in westerly D and 42 gammas in H and a fall of 15

[1]Communicated by Dr. S. R. Savur, Director, Bombay and Alibag Observatories.

gammas in Z. H fluctuated with small-period oscillation till $05^h 08^m$, after which it rose rapidly to reach its maximum at $05^h 38^m$. Then a fall occurred till $07^h 06^m$ after which H rose again. At $07^h 21^m$ H began to fall rapidly and continued so till $09^h 27^m$, the amount of fall during this interval being about 354 gammas. After a gradual rise in H till $13^h 13^m$, H fell rapidly by 334 gammas in forty-six minutes. At $13^h 59^m$ the H trace went off the photogram for about 96 minutes. At $15^h 35^m$ the trace was brought within the recording limit of the magnetogram by the use of a control magnet. At $15^h 39^m$ a further large decrease in H occurred resulting in loss of record which it was not possible to prevent. The H trace reappeared on the magnetogram at $17^h 48^m$ and the oscillations grew feebler thereafter. The storm practically ended at $23^h.5$, March 1, though the value of H was about 265 gammas below the pre-storm value. Ranges: D, 16′; H, >785 gammas; Z, 130 gammas.

March 13-14—A slight disturbance which later developed into a moderate one commenced gradually at about $15^h.5$ GMT, March 13. The oscillations in H became more pronounced after $0^h.5$, March 14. H attained its maximum at $06^h 27^m$, March 14, and then began to fall reaching the minimum at $11^h 10^m$, March 14. The disturbance ended at about $23^h.5$, March 14. Ranges: D, 5′.7; H, 174 gammas; Z, 41 gammas.

March 19—A moderate disturbance commenced at about 05^h GMT, March 19. H reached its maximum at $06^h 25^m$ and the minimum at $13^h 36^m$. The disturbance practically ended at 19^h, though minor oscillations continued for some hours later. Ranges: D, 4′.0; H, 178 gammas; Z, 12 gammas.

March 28-29—A moderate disturbance with a gradual commencement began at about 04^h GMT, March 28. H rose to reach its maximum at $05^h 18^m$, March 28, and then began to fall with oscillations by stages. The minimum in H was recorded at $15^h 28^m$. Rapid fluctuations continued till $20^h.5$, March 28, when the disturbance became very much feebler. Oscillations to a more or less degree continued till $23^h.5$, March 29, when the disturbance practically ended. Ranges: D, 5′.8; H, 213 gammas; Z, 61 gammas.

March 30-31—A moderate disturbance with a sudden commencement of 44 gammas in H began at $16^h 39^m$ GMT, March 30. H reached its maximum at $17^h 08^m$, March 30, and the minimum at $11^h 38^m$, March 31. The disturbance practically ended at 13^h, March 31. Ranges: D, 7′.6; H, 200 gammas; Z, 30 gammas.

Bombay Observatory, India M. R. Rangaswami

Huancayo Magnetic Observatory

April to June, 1941

(Latitude 12° 02′.7 S., longitude 75° 20′.4 or $5^h 01^m.4$ W. of Gr.)

April 7—Small disturbances began at about 09^h GMT, April 7. Large bays developed on all traces from 23^h to 24^h. Ranges: D, 14′; H, 60 gammas; Z, 62 gammas.

April 9-11—This period was moderately disturbed.

April 18—There were bays in all traces from 22^h to 23^h GMT, April 18. Ranges: D, 16′; H, 61 gammas; Z, 58 gammas.

April 19—This was a moderately disturbed day. Ranges: D, 15′; H, 58 gammas; Z, 61 gammas.

April 24-26—There was a moderate magnetic disturbance beginning shortly after 07^h GMT, April 24, which was characterized by a series of small peaks and bays and a marked decrease in H for about 24 hours. D and Z were also mildly disturbed during the daylight hours of April 24. This storm continued until 12^h, April 26. Ranges, April 24: D, 45′; H, 180 gammas; Z, 121 gammas.

April 28-29—The period from 19^h GMT, April 28, to 03^h, April 29, was moderately disturbed.

May 4—There was a small sudden commencement at $03^h\,05^m$ GMT, May 4, with an increase of 22 gammas in H in five minutes. The storm died down after about twelve hours. Ranges: D, 16′; H, 78 gammas; Z, 55 gammas.

May 21-25—Moderate disturbances began at 17^h GMT, May 21, and continued until the end of May 25.

June 9—There was a sudden commencement at $09^h\,12^m$ GMT, June 9, with an increase of 25 gammas in H in five minutes. For the few following hours the fluctuations were small. Ranges: H, 61 gammas; Z, 66 gammas.

June 10-11—A sudden commencement began at $13^h\,05^m$ GMT, June 10, with an increase of 25 gammas in H in five minutes. This small storm continued until 21^h, June 11.

June 13-15—There was a small sudden commencement at $03^h\,14^m$ GMT, June 13, with an increase of 7 gammas in H in five minutes. Disturbances continued until the end of June 15. Ranges: D, 17′; H, 97 gammas; Z, 71 gammas.

June 16-17—This mild magnetic disturbance began suddenly at $17^h\,28^m$ GMT, June 16, with a sharp decrease in H of 62 gammas in four minutes followed by a slow rise and at $18^h\,50^m$ there was a second rapid decrease of 151 gammas in seven minutes. After a moderate increase, H fell slowly to a very low value during the hours from 23^h, June 16, to 02^h, June 17. Recovery to normal values was practically complete by 07^h, June 17.

June 20-21—There were moderate disturbances from 20^h GMT, June 20, to 04^h, June 21, with bays from 23^h, June 20, to 01^h, June 21. Ranges: D, 19′; H, 45 gammas; Z, 48 gammas.

Paul G. Ledig, *Observer-in-Charge*

Watheroo Magnetic Observatory

April to June, 1941

(Latitude 30° 19′.1 S., longitude 115° 52′.6 or $7^h\,43^m.5$ E. of Gr.)

April 24-25—A small magnetic disturbance began with a sudden commencement in all three elements at $07^h\,20^m$ GMT, April 24. For the following 24 hours the traces were only moderately active, the most important features being: (*a*) A gradual decrease of H between $08^h\,30^m$ and $09^h\,40^m$ of 134 gammas; (*b*) a small rapid double oscillation shown in all three elements at $13^h\,30^m$. By 08^h, April 25, the traces had regained the normal characters. A small group of sunspots was ob-

served on both days but no activity was seen during the periods of observation. Ranges: D, 22′; H, 148 gammas; Z, 144 gammas.

There were only minor disturbances recorded at Watheroo during May and June, 1941.

W. C. Parkinson, *Observer-in-Charge*

Hermanus Magnetic Observatory

January to June, 1941

(Latitude 33° 57′ S., longitude 18° 28′ or 1h 13m.9 E. of Gr.)

January 1—The period from 12h to 18h GMT was moderately disturbed.

January 5-9—A storm began with a small commencement at 15h 45m GMT, January 5, with an increase of 11 gammas in H in four minutes. The storm continued until 01h, January 7. There were further disturbances on January 7 in the period from 15h to 21h and on January 9 from 12h to 15h. The ranges of H were of the order of 70 gammas.

January 16-21—This storm began with a gradual commencement at 21h GMT, January 16, and continued until the end of January 19. There was a recurrence of the storm at 18h 56m, January 20, which lasted until 06h, January 21.

January 23-24—The period from 12h to 21h GMT, January 23, was disturbed. Ranges: H, 126 gammas; Z, 96 gammas. Again on January 24 there was a disturbed period from 09h to 21h. Ranges: H, 82 gammas; Z, 92 gammas.

February 3—Disturbances occurred in the period from 08h to 24h GMT, February 3. Ranges: H, 96 gammas; Z, 64 gammas.

February 13-14—A gradual commencement storm started at 00h GMT, February 13, and continued throughout the day followed by small disturbances on February 14.

February 21—A gradual commencement storm started at about 09h GMT, February 21, and continued until the end of the day. Ranges: H, 82 gammas; Z, 107 gammas.

February 28—There was a very small sudden commencement disturbance at 15h 26m GMT, February 28, of about one hour's duration.

March 1—The ranges recorded during the storm of March 1, 1941, were larger than those of any storm which had been experienced at the Cape Town Magnetic Observatory, which was established in August, 1932. Figure 1 shows the record of the storm at the Hermanus Magnetic Observatory, which is about 80 miles from Cape Town. The Z-trace was not quite complete but it was possible to approximate the missing portion from the time-marks recorded by the mirror. This intense storm began at 03h 58m GMT, March 1, with a sudden commencement, H increasing by 42 gammas and D moving 1′.4 east within an interval of two minutes. A further sudden increase of 48 gammas in H occurred at 05h 19m and was accompanied by a deflection of 1′.0 in D in two minutes, from a maximum value at 06h 09m, H decreased by 369 gammas until 09h 10m. An increase in H of 197 gammas followed until 13h 12m, with a sharp increase of 23 gammas in one minute at 12h 29m. There followed a rapid decrease of 384 gammas to the minimum of the storm at

16ʰ 51ᵐ. Recovery was rapid until 17ʰ 08ᵐ from which time H returned gradually to normal values; small fluctuations occurring until 22ʰ. Large variations occurred in declination. There was an easterly trend in the first phase of the storm which lasted until about 07ʰ and then a small westerly movement to a minimum at about 15ʰ and then a sudden easterly movement to a maximum at about 18ʰ. During the second rapid fall in H between 13ʰ 05ᵐ and 14ʰ 14ᵐ, D moved rapidly westward 11′.0. Ranges: D, 85′; H, 614 gammas; Z, >640 gammas. Ranges of

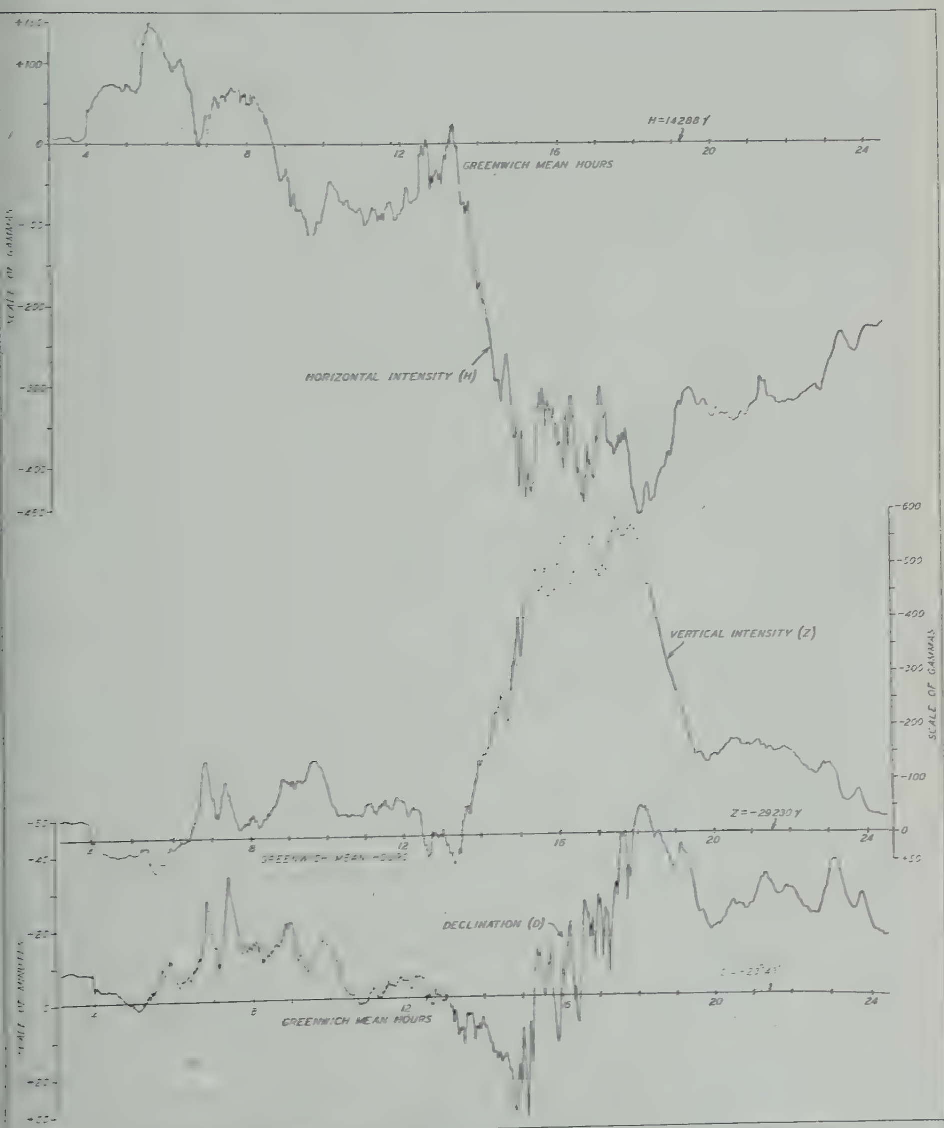


FIG. 1—MAGNETOGRAM RECORDED MARCH 1, 1941, HERMANUS MAGNETIC OBSERVATORY, SOUTH AFRICA

the storm at Cape Town April 16, 1938, were D, 101′, H, 578 gammas, and Z, 573 gammas; ranges of the storm at Cape Town March 24, 1940, were D, 91′, H, 521 gammas, and Z, 522 gammas. The average of three-hour-indices for the 7 periods of the intense storm of March 1, 1941, is 7.

March 30-31—A weak disturbance appeared with a sudden commencement at $16^h 36^m$ GMT, March 30. H increased 26 gammas and easterly declination increased 0′.5, while the numerical value of Z increased by 10 gammas. Moderate activity continued until 13^h, March 31.

April 7—Small disturbances started at about 09^h GMT, April 7. Large bays developed on all traces from 23^h to 24^h. Ranges: D, 14′; H, 60 gammas; Z, 62 gammas.

April 9-11—The period April 9-11 was moderately disturbed.

April 18—Bays on all traces from 22^h to 23^h GMT, April 18. Ranges: D, 16′; H, 61 gammas; Z, 58 gammas.

April 19—April 19 was moderately disturbed. Ranges: D, 15′; H, 58 gammas; Z, 61 gammas.

April 24-26—A storm started at about 07^h GMT, April 24, and continued until 12^h, April 26. Ranges, April 24: D, 45′; H, 180 gammas; Z, 121 gammas.

April 28-29—The period from 19^h GMT, April 28, to 03^h, April 29, was moderately disturbed.

May 4—A small sudden commencement started at $03^h 05^m$ GMT, May 4, with an increase of 22 gammas in H in five minutes. The storm died down after about twelve hours. Ranges: D, 16′; H, 78 gammas; Z, 55 gammas.

May 21-23—Moderate disturbances began at 17^h GMT, May 21, and continued through 24^h, May 23.

June 9—A sudden commencement storm started at $09^h 12^m$ GMT, June 9, with an increase of 25 gammas in H in five minutes. The fluctuations were small and lasted only a few hours. Ranges: H, 61 gammas; Z, 66 gammas.

June 10-11—A sudden commencement began at $13^h 05^m$ GMT, June 10, with an increase of 25 gammas in five minutes in H. This small storm continued until 21^h, June 11.

June 13-15—A small sudden commencement started at $03^h 42^m$ GMT, June 13, with an increase of 7 gammas in five minutes in H. The disturbances continued until 24^h June 15. Ranges: D, 17′; H, 97 gammas; Z, 71 gammas.

June 20-21—There were moderate disturbances from 20^h GMT, June 20, to 04^h, June 21, with bays from 23^h to 01^h. Ranges: D, 19′; H, 45 gammas; Z, 48 gammas.

A. OGG, *Magnetic-Survey Adviser*

NOTES

17. *Seventh Pacific Science Congress*—If world conditions permit, it is planned to hold the Seventh Pacific Science Congress at Manila in 1943, probably about November, under the auspices of the National Research Council of the Philippines. Several symposia on subjects of general interest to the Pacific are under consideration.

18. *Magnetic field-work in Argentina*—During the period 1937-40, 90 magnetic field-stations were occupied in Argentina, several of which were exact reoccupations of stations established by observers of the Carnegie Institution of Washington. One observer is continually maintained in the field and it is expected that at least 35 additional stations will be occupied by the end of the current year. By the end of 1942 reoccupation of all the old stations is anticipated. A new magnetic chart of the Republic of Argentina will then be issued.

19. *Liangfeng Magnetic Observatory*—A new magnetic observatory is being erected at Liangfeng about 22 km south of Kweilin, Kwangsi Province, China. It will be provided with the instruments previously in operation at the Nanking Magnetic Observatory which had to be abandoned early in the war. It is expected that the Observatory will be completed by the end of August, 1941. Parker C. Chen, who received training in magnetic work in Germany, will be chief of the new Observatory and it is hoped that the regular work will be resumed very soon.

20. *Cheltenham Magnetic Observatory*—The insensitive instruments gave an excellent record of the magnetic storm of July 5, 1941, despite the fact that for four successive periods the three-hour range index was 9.

21. *Tucson Magnetic Observatory*—An improved magnetograph has been installed in the new variation-building at Tucson, Arizona, but the observations were continued in the old building for a suitable length of time to obtain a good comparison between the two installations. This was especially important as the new building is partly underground.

22. *San Juan Magnetic Observatory*—John Hershberger of the staff of the Cheltenham Observatory is at present at the San Juan Observatory installing an improved magnetograph. The program also includes replacing the obsolete instruments with modernized ones. A joint magnetic and ionospheric Work Projects Administration program has reached a point where correlated results are being obtained at the Observatory.

23. *Polar-Year observations*—A Works Projects Administration computing office in New York City is making it possible to complete the work on the records of all United States Coast and Geodetic Survey observatories for the second Polar Year, 1932-33. Much of the revised information is available at the office of the Coast and Geodetic Survey, and publication of the results will begin soon.

24. *Magnetic disturbances, Caribbean Sea and North Pacific Ocean*—We reprint the following interesting notes from the United States *Hydrographic Bulletin* [No. 2708, July 30, 1941].

An observer reports that at 19:50 GMT, on July 5, 1941, in latitude 17° 32′ north, longitude 81° 54′ west, when making the routine half-hourly comparison of the compasses, the magnetic standard and steering compasses read 010° while the ship was on a true and gyrocompass heading of 329°. The normal magnetic compass heading for this true course was 327°. A spare magnetic compass was rigged to check this magnetic condition and it too gave an identical reading. An azimuth of the Sun was taken and the gyrocompass was found to be without error. The magnetic compasses returned slowly to the normal magnetic heading, swung past this heading, and continued swinging until a heading of 309° was reached. They remained on this heading for a while and then swung back to the normal heading where they remained. At 21:15 GMT, in latitude 17° 57′ north, longitude 82° 11′ west, this abnormal magnetic condition had entirely disappeared. The following tabulation gives the readings of the compasses:

Time (GMT)		Steering Compass	Standard Compass	Gyrocompass
h	*m*	°	°	°
19	50	010	010	329
20	10	351	349	329
20	25	320	320	329
20	30	312	315	329
20	35	309	310	329
20	55	315	317	329
21	15	327	329	329

An observer reports that at 09:10, ship's time (19:10 GMT), on May 11, 1941, in latitude 33° 06′ north, longitude 151° 38′ west, while steering 270°.3, true (270° per gyrocompass-error 0°.3 east), speed 14.3 knots, the standard and wheelhouse magnetic compasses checked 260° during the routine half-hourly check instead of 254°, the normal magnetic compass-course. The gyrocompass-repeaters were checked with the master-gyrocompass and found to be correct and an azimuth was taken which gave an error of the gyro of 0°.3 east. At 09:22 the magnetic compasses checked 264°; at 09:35, 254°; at 10:03, 250°; and at 10:31, 254°, where they settled.

25. *Geophysical Institute, Potsdam, Germany*—A report from Dr. J. Bartels indicates the storm of March 1, 1941, as the greatest ever recorded at Niemegk where the ranges were 4° 26′ (1417 gammas) in *D*, 2115 gammas in *H*, and 1687 gammas in *Z*.

26. *Corrected mean magnetic character-numbers for each day of* 1939—The final publication of magnetic-characters for 1939 has been received and there are a number of small corrections required in Tables 1 and 2 as published in the Journal [45, 351-352 (1940)]. The two tables with corrected values are therefore printed below.

27. *Corrigenda*—In the June 1941 number of the Journal the following corrections are noted. On page 172 in the fifth last line of the last paragraph of §15 read "deposit" instead of desposit."

On page 178 make equation (2) read "$D_2=2\pi\rho^4\epsilon/5l$" instead of "$D_2=2\pi\rho^4\epsilon/\sigma l$"; on page 211 the entry in Table D for June, 1855, should read "670" instead of "570." (K. F. Wasserfall, in a letter dated June 10, 1941, states that all of the daily values of H at 09^h and 14^h for the entire interval are now published in his article "The horizontal component of magnetic intensity at Oslo Observatory 1843-1930 (daily values for 9 and 14 o'clock)" in *Geofysike Publikasjoner* [**13**, No. 2, Oslo, 1941].)

ABLE 1—*Mean magnetic character-numbers for each day of 1939 from data supplied by observatories*

Month	Dates														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1939															
anuary	0.1	0.3	0.1	0.2	1.0	0.7	0.6	0.7	1.0	0.8	0.8	0.3	0.2	0.4	0.4
ebruary	1.3	1.2	0.9	0.5	1.1	1.8	1.3	0.7	0.9	1.1	0.8	0.0	0.3	0.5	1.0
larch	1.4	1.3	1.3	1.3	0.8	0.8	0.4	0.9	1.1	0.6	1.0	0.9	0.4	0.5	1.1
pril	1.2	1.0	0.9	1.1	0.8	0.3	0.2	0.8	1.1	1.4	1.4	1.0	0.5	0.5	0.2
lay	1.8	1.5	1.0	0.5	1.4	1.6	1.5	1.5	1.2	0.4	0.3	0.2	0.5	0.1	0.6
une	0.9	1.2	1.0	1.1	0.7	0.3	0.2	0.2	0.1	0.5	0.2	0.3	1.0	1.8	0.8
uly	0.7	0.6	1.7	1.7	2.0	0.8	0.0	0.3	0.2	0.1	1.0	0.9	0.2	1.4	0.7
ugust	0.2	0.0	0.1	0.3	0.1	0.1	0.1	0.3	0.1	0.9	1.2	2.0	1.4	0.5	0.3
eptember	0.2	0.9	1.5	0.4	0.3	0.5	0.4	0.4	1.4	1.1	0.3	0.7	0.4	0.7	0.3
ctober	0.6	0.3	1.7	1.6	1.2	1.4	1.0	0.6	1.4	0.3	0.7	0.1	2.0	1.9	1.8
ovember	0.5	0.2	0.5	0.2	0.3	0.5	0.4	0.1	0.2	0.1	0.5	0.9	1.6	1.1	0.7
ecember	0.6	0.4	0.5	0.3	1.0	1.4	1.7	1.4	1.1	0.8	0.4	0.8	0.3	0.1	0.4

Month	Dates																Means
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1939																	
anuary	0.8	1.0	0.5	0.4	0.6	1.1	1.0	0.8	0.5	0.2	0.0	0.0	0.4	0.3	0.1	0.2	0.51
ebruary	1.1	1.1	0.9	0.9	0.5	0.1	0.1	0.6	2.0	1.9	0.5	0.3	0.8				0.87
larch	1.1	0.8	0.2	0.4	0.5	1.3	1.5	1.2	0.8	0.4	0.9	1.4	1.8	1.9	1.4	1.0	0.98
pril	0.4	2.0	1.5	1.6	1.2	1.1	1.2	1.9	1.9	1.7	0.6	0.9	0.9	0.8	0.5		1.19
lay	1.1	0.7	0.4	0.8	0.8	1.2	1.3	1.3	1.3	1.2	0.9	0.8	1.2	1.4	0.3	0.2	0.94
une	1.3	0.3	1.2	1.2	0.9	1.1	0.7	0.7	0.5	0.3	1.1	1.2	1.1	1.3	0.9		0.79
uly	1.2	1.1	0.6	0.9	1.6	1.7	1.1	0.7	0.7	0.8	1.5	0.7	0.5	0.3	0.2	0.2	0.84
ugust	1.8	1.1	0.5	1.0	0.4	0.8	2.0	1.8	0.9	0.5	0.4	0.4	0.3	0.3	0.6	0.2	0.67
eptember	0.4	1.7	0.5	1.4	1.4	0.6	0.8	0.3	0.2	0.9	1.2	0.4	0.1	0.1	0.8		0.67
ctober	1.5	1.3	1.3	1.0	0.1	0.8	0.5	1.1	0.4	0.2	0.4	0.1	0.6	0.5	0.5	0.3	0.88
ovember	0.2	0.3	0.1	0.8	0.3	0.2	0.0	0.1	0.8	1.2	1.0	0.4	0.4	0.5	0.4		0.48
ecember	0.8	0.3	0.0	0.0	0.2	1.3	1.3	0.8	0.6	0.4	0.3	1.1	0.7	0.6	0.4	0.1	0.64
																	0.775

Table 2—*Dates of five magnetically calm and five disturbed days with mean character-numbers duri*

Month	Calm days						Disturbed days				
1939											
January	(0.08)	**1**,	**3**,	**26**,	**27**,	**30**	**5** (1.0),	**9** (1.0),	**17** (1.0),	**21** (1.1),	**2**
February	(0.17)	**12**,	**13**,	**21**,	**22**,	**27**	**1** (1.3),	**6** (1.8),	**7** (1.3),	**24** (2.0),	**2**
March	(0.37)	**7**,	**13**,	**18**,	**19**,	**25**	**22** (1.5),	**27** (1.4),	**28** (1.8),	**29** (1.9),	**3**
April	(0.31)	**6**,	**7**,	**13**,	**15**,	**16**	**17** (2.0),	**18** (1.5),	**23** (1.9),	**24** (2.0),	**2**
May	(0.25)	**11**,	**12**,	**13**,	**14**,	**31**	**1** (1.8),	**2** (1.5),	**6** (1.6),	**7** (1.5),	
June	(0.17)	**7**,	**8**,	**9**,	**11**,	**25**	**14** (1.8),	**16** (1.3),	**19** (1.2),	**27** (1.2),	**2**
July	(0.14)	**7**,	**9**,	**10**,	**13**,	**30**	**3** (1.7),	**4** (1.7),	**5** (2.0),	**20** (1.6),	**2**
August	(0.07)	**2**,	**3**,	**5**,	**6**,	**7**	**12** (2.0),	**13** (1.4),	**16** (1.8),	**22** (2.0),	**2**
September	(0.18)	**1**,	**5**,	**24**,	**28**,	**29**	**3** (1.5),	**9** (1.4),	**17** (1.7),	**19** (1.4),	**2**
October	(0.18)	**12**,	**20**,	**25**,	**27**,	**31**	**3** (1.7),	**4** (1.6),	**13** (2.0),	**14** (1.9),	**1**
November	(0.10)	**8**,	**10**,	**18**,	**22**,	**23**	**12** (1.0),	**13** (1.6),	**14** (1.1),	**25** (1.2),	**2**
December	(0.09)	**14**,	**18**,	**19**,	**20**,	**31**	**6** (1.4),	**7** (1.7),	**8** (1.4),	**21** (1.3),	**2**

28. *Personalia—John Patterson*, Controller of the Meteorological Service of Canada, has been awarded the high distinction of election to honorary membership in the Royal Meteorological Society of London. Mr. Patterson became Assistant Director of the Canadian Meteorological Service in 1925 and Director in 1929. The Agincourt and Meanook observatories were operated under his direction until the recent governmental reorganization when his title was changed to Controller. He took a very active part in the organization of the auroral and magnetic expeditions in Canada during the International Polar Year 1932-33.

We regret to record the death on June 22, 1941, of *C. W. Jeffries*, Director of the Royal Observatory, Hongkong, since 1932.

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Agincourt and Meanook Observatories. Record of observations at the magnetic observatories Agincourt and Meanook 1930. By W. E. W. Jackson. Ottawa, Dept. Transport, Air. Serv. Branch, Div. Met. Serv., 67 pp. (1939).

Anderson, C. N. Transit times—a factor in solar-terrestrial disturbances. The Sky, New York, **5**, No. 10, 10-11 (1941).

Batavia. Observations made at the Royal Magnetical and Meteorological Observatory at Batavia, v. 58 B, 1935. Magnetic observations. Published by order of the Government of the Netherlands Indies, by J. Boerema, Director. Batavia, vii+22 (1940). [Contains magnetical records Batavia-Kuyper 1935.]

Besairie, H. Le réseau magnétique de Madagascar au 1er janvier 1938. Toulouse, Bull. Soc. Hist. Nat., **76**, 53-56 (1941).

Berkner, L. V. Contributions of ionospheric research to geomagnetism. Proc. Amer. Phil. Soc., **84**, 309-321 (1941).

Chapman, S. Notes on isomagnetic charts: V—The occurrence of local dip-poles. Terr. Mag., **46**, No. 2, 163-172 (1941).

Elsasser, W. M. Statistical analysis of the Earth's internal magnetic field. Abstract, Phys. Rev., **60**, No. 2, 159 (1941). [It is shown that, if the Earth's magnetic field is due to a finite number of dipoles distributed at random over a concentric spherical shell, the most probable radius of the shell is approximately one half that of the Earth.]

Fleming, J. A. Geomagnetism: World-wide and cosmic aspects with especial reference to early research in America. Proc. Amer. Phil. Soc., **84**, No. 2, 263-298 (1941).

Hagihara, H., and Y. Honna. A statistical investigation of K.-H. layer and its relation to the annual variation of terrestrial magnetism. J. Met. Soc. Japan, **19**, No. 5, 187-192 (1941). [Japanese text with brief English abstract on pp. (19)-(20).]

Heck, N. H. The magnetic survey of the United States. Proc. Amer. Phil. Soc., v. **84**, No. 2, 1941 (205-224).

Hongkong, Royal Observatory. Magnetic results 1939. Prepared under the direction of C. W. Jeffries, Director. Hongkong, Noronha and Co., Govt. Printers, 51 pp. (1940). 33 cm.

Howe, H. H. Secular change at Cheltenham, Maryland. Terr. Mag., **46**, No. 2, 246 (1941).

Johnston, H. F. Three-hour-range indices, *K*, for twelve magnetic observatories, January to June, 1940. Terr. Mag., **46**, No. 2, 239-244 (1941).

Magnetic work at sea. Proc. Amer. Phil. Soc., **84**, No. 2, 257-262 (1941).

Jones, W. M. Magnetic observations of North Auckland serpentinites. N. Z. J. Sci. Tech., Wellington, **22**, No. 2B, 117B-123B (1940). [Anomalies of vertical magnetic intensity have been mapped over some of the serpentinite outcrops in the Silverdale-Warkworth district, and deductions made as to the size and shape of the outcropping bodies. At Whitehills, near Silverdale, a belt of anomaly extending for at least half a mile, with a range of 1,500 gammas, was found adjacent to two small outcrops of serpentinite. A bore of 8 feet encountered a contact alteration of the clays, and the rock responsible for the anomaly is probably only about 10 feet from the surface at this point.]

LAHAYE, E. Aperçu sur les phénomènes magnétiques terrestres associés à des phénomènes électriques de la haute atmosphère. Ciel et Terre, **56**, No. 12, 313-341 (1940).

McCOMB, H. E. Geomagnetic observatories and instruments. Proc. Amer. Phil. Soc., **84**, No. 2, 239-255 (1941).

N., H. W. Magnetic storms and solar activity during 1940. Observatory, **64**, No. 800, 28-29 (1941).

The great magnetic storm of 1941, March 1. Observatory, **64**, No. 802, 82-86 (1941).

McNISH, A. G. The significance of fossil magnetism. Proc. Amer. Phil. Soc., **84**, No. 2, 225-237 (1941).

NARAYANASWAMI, R. The daily variation of irregular disturbances of the Earth's magnetic field at Bombay. Terr. Mag., **46**, No. 2, 147-162 (1941).

ÓGYALLA. Bulletin mensuel de l'Observatoire royal pour la Météorologie et le Magnétisme terrestre, décembre 1939, et janvier à décembre 1940. Budapest, Obs. R. Mét. Mag. Terr., **1**, No. 12, 111-120 (1940); **2**, Nos. 1-12, 120 pp. (1940-1941).

PRINCIPAL MAGNETIC STORMS. Principal magnetic storms. January to March, 1941. Terr. Mag., **46**, No. 2, 256-262 (1941). [Storms reported for Huancayo Magnetic Observatory are for December, 1940, to March, 1941; those for Alibag Magnetic Observatory and Capetown Magnetic Observatory are for October to December, 1941.]

RIO DE JANEIRO, OBSERVATÓRIO NACIONAL. Boletim magnético do Observatório Nacional 1929 a 1934. Rio de Janeiro, Imprensa Nacional, 231 pp. (1938). 33 cm.

WASSERFALL, K. F. Magnetic horizontal intensity at Oslo, 1843-1930. Terr. Mag., **46**, No. 2, 173-218 (1941).

B—Terrestrial and Cosmical Electricity

ARAKAWA, H. Seasonal and diurnal variations of cosmic-ray intensity. Bull. Amer. Met. Soc., **22**, No. 4, 184-185 (1941).

BLACKETT, P. M. S. Cosmic rays: recent developments. Proc. Phys. Soc., **53**, No. 297, 203-213 (1941).

BROXON, J. W. Geomagnetic character and cosmic-ray intensity pulses. Phys. Rev., **59**, No. 8, 678-679 (1941).

Recurrence phenomena in cosmic-ray intensity. Phys. Rev., **59**, No. 10, 773-776 (1941).

BRUCE, C. E. R. The lightning and spark discharge. Nature, **147**, 805-806 (June 28, 1941).

BRUCE, C. E. R., AND R. H. GOLDIE. The lightning discharge. Abstract, J. Inst. Elec. Eng., **88**, I, No. 6, 242-245 (1941).

CARLSON, J. F., AND M. SCHEIN. On the production of mesotrons. Phys. Rev., **59**, No. 10, 840 (1941).

CHALMERS, J. A. The effective separation on points discharging atmospheric electricity. Phil. Mag., **31**, No. 308, 363-372 (1941).

FERRELL, E. J., AND N. E. BRADBURY. Atmospheric potential gradient at exposed coastal stations. Abstract, Phys. Rev., **60**, No. 2, 161 (1941).

GAGE, M., AND F. A. McNEILL. Geophysical investigations in the area between Waiuta and Merrijigs. N. Z. J. Sci. Tech., Wellington, **22**, No. 3B, 155B-165B (1941).

GARTLEIN, C. W. Aurora and geomagnetism. Proc. Amer. Phil. Soc., **84**, No. 2, 299-307 (1941).

GAST, P. F., AND D. H. LOUGHRIDGE. Cosmic rays in the Bering Sea. Phys. Rev., **59**, No. 9, 769-770 (1941).

GILL, P. S. Azimuthal variations of cosmic radiation for 60° zenith angle at 22° latitude. Phys. Rev., **60**, No. 2, 153 (1941).

GISH, O. H. Terrestrial electricity in relation to geomagnetism. Proc. Amer. Phil. Soc., **84**, 187-204 (1941).

GOLDE, R. H. The validity of lightning tests with scale methods. J. Inst. Elec. Eng., **88**, II, No. 2, 67-68 (1941).

GROSS, B. Ueber den Breiteneffekt der kosmischen Strahlung. Acta Pontif. Acad. Sci., **4**, No. 7, 49-60 (1940).

HALLIDAY, E. C. The thundercloud as a source of penetrating particles. Phys. Rev., **60**, No. 2, 101-106 (1941). [The paper describes cloud-chamber experiments designed to test the hypothesis that the electrostatic fields in thunderclouds can produce showers of electrons with energies as great as those found in the penetrating radiation. 65 thunder-storms were observed and 5000 photographs of electron tracks were taken, together with 4500 control photographs. A statistical examination of the relative number of penetrating electron tracks seen in the two sets of photographs indicates a very strong possibility that penetrating electrons are rejected from thunderclouds and reach the Earth at considerable distances from the clouds. There is thus evidence that storm clouds act as a source of penetrating electrons, but it is not known whether they are the only source. The experiments indicate that the simple hypothesis, that the penetrating electrons, after their ejection from the storm clouds travel in helical paths about the Earth's magnetic field, is untenable.]

HARANG, L. Das Polarlicht und die Probleme der höchsten Atmosphärenschichten. Leipzig, Akademische Verlagsgesellschaft Becker und Erler Kom.-Ges., viii+120 mit 72 Fig. und 17 Tabellen im Text (1940).

HILBERRY, N. The energy distribution and composition of the primary cosmic-ray particles. Phys. Rev., **59**, No. 9, 763-764 (1941).

Extensive cosmic-ray showers and the energy distribution of primary cosmic rays. Phys. Rev., **60**, No. 1, 1-9 (1941).

ITO, K. The relation between smoke particles and condensation-nuclei. J. Met. Soc. Japan, **19**, No. 3, 88-95, (10), (1941). [Japanese text with English abstract].

The relation between visibility and atmospheric suspensoids. J. Met. Soc. Japan, **19**, No. 3, 96-103 (10)-(11), (1941).

JÁNOSSY, L., AND P. LOCKETT. The Sun's magnetic field and the diurnal and seasonal variations in cosmic ray intensity. Proc. R. Soc., A, **178**, No. 972, 52-60 (1941).

KOLHÖRSTER, W. Der Tagesgang der Höhenstrahlung. Physik, Zs., **42**, No. 2/3, 55-57 (1941).

KORFF, S. A. Nuclear particles in the cosmic radiation. Phys. Rev., **59**, No. 12, 949-954 (June 15, 1941).

LIEBERMANN, K. Nordlichtbeobachtung. Zs. Geophysik, **16**, Heft 7/8, 333 (1940). [Brief description of auroral display observed at Danzig December 20, 1940.]

MICHEL, G. Zum Grundproblem der atmosphärischen Elektrizität. Zs. Physik, **117**, Heft 3/4, 205-212 (1941).

MOM, C. P. Der Einfluss der Luftelektrizität auf die Behaglichkeit und die Gesundheit. Gesundh.-Ing., **63**, 468-471 (1940).

MÜLLER, M. Ergebnisse geoelektrischer Polarisationsmessungen. Zs. Geophysik, **16**, Heft 7/8, 274-284 (1940).

NISHINA, Y., Y. SEKIDO, AND H. SIMAMURA. Cosmic-ray intensities and typhoons. Phys. Rev., **59**, No. 8, 679 (1941).

NOLAN, P. J. The recombination law for weak ionization. Nature, **148**, 26 (July 5, 1941).

NOTO, H. Some studies on thunderstorms. Part V. Jap. J. Astr. Geophys., **18**, No. 1, 73-87 (1940).

PERRY, F. R. The measurement of lightning voltages and currents in South Africa and Nigeria, 1935 to 1937. J. Inst. Elec. Eng., **88**, II, No. 2, 69-87 (1941). Abstract, *ibidem*, **88**, I, No. 7, 270-273 (1941).

SWANN, W. F. G. A single component for the primary cosmic radiation. Phys. Rev., **59**, No. 9, 770-771 (1941).

Further evidence for a single component in the primary cosmic radiation. Phys. Rev., **59**, No. 10, 836 (1941).

ZIEMKE, P. C. Electrical hazards presented by static electricity and earth-currents. With a summary of requirements for shot-firing underground. Eng. Min. J., **141**, No. 6, 42-45 (1940).

C—Miscellaneous

ARLICK, A. B. Possible Earth's field effect on atmospheric spectrum intensities. Science and Culture, **6**, No. 8, 486-487 (1941).

BARBER, D. R. Studies in night-sky photometry. Lick. Obs. Bull., No. 505, 105-114 (1941). [The author concludes that, from experimental results presented in the paper, concrete evidence has been obtained regarding the suspected correlation between the measures of the light of the night sky and the terrestrial-magnetic elements. It would appear that the brightness level is determined solely by the degree of ionization produced in the high atmosphere during hours of insolation and that the relatively frequent, irregular fluctuations of brightness which occur during the night arise in some degree from the same cause as that responsible for the similar perturbations of the magnetic elements. The author finds further that the phenomenon of the night-sky light is intimately related to polar auroras, variation of the magnetic elements, and solar activity.]

BARNÓTHY, J., AND M. FORRÓ. Proper lifetime of the mesotrons. Phys. Rev., **60**, No. 2, 154 (1941).

BRUNNER, W. Final relative sunspot-numbers for 1940. Terr. Mag., **46**, No. 2, 219-221 (1941).

Provisional sunspot-numbers for February to April, 1941. Terr. Mag., **46**, No. 2, 222 (1941).

CHAPMAN, S. The Sun as a producer of energy. Nature, **147**, 792-794 (June 28, 1941). [From the earlier part of the thirty-second Kelvin Lecture to the Institution of Electrical Engineers, entitled "The Sun and the ionosphere."]

DEB, A. C. Temperature of the upper atmosphere. Science and Culture, **6**, No. 9, 502-507 (1941).

Penetration of thin ionospheric layers. Indian J. Phys., **14**, Pt. 6, 451-457 (1941).

ENGLISH, R. A. J. Preliminary account of the United States Antarctic Expedition. Geog. Rev., **31**, No. 3, 466-478 (1941).

EVANS, R. D. Atom smashing and its applications to medicine. Elec. Eng., **60**, No. 6, 250-260 (1941).

FEATHER, N. Ionization maximum for protons. Nature, **147**, 510-511 (April 26, 1941).

FENDLER, E. Die ionosphärisch bedingte Uebertragung ultrakurzer Wellen. Hochfrequenztech., **56**, No. 2, 41-47 (1940).

GILLILAND, T. R., AND A. S. TAYLOR. Field equipment for ionospheric measurements. J. Res. Bur. Stan., **26**, No. 5, 377-384 (1941).

HALLBORG, H. E. Correlations of short wave radio transmission across the Atlantic with magnetic conditions. Proc. Amer. Phil. Soc., **84**, 323-337 (1941).

HARRADON, H. D. List of recent publications. Terr. Mag., **46**, No. 2, 263-267 (1941).

HECHTEL, R. Ueber einen Zusammenhang zwischen dem Licht des Nachthimmels und der Ionosphäre. Hochfrequenztech., **56**, Heft 5, 129-136 (1940).

HEYL, P. R. Magnetism and its uses. Proc. Amer. Phil. Soc., **84**, 339-351 (1941).

JOHNSTON, H. F. American *URSI* broadcasts of cosmic data, giving American magnetic character-figure, C_A, three-hour-range indices, K, and mean K-indices, K_A, for January to March, 1941. Terr. Mag., **46**, No. 2, 248-252 (1941).

KOBAYASI, M. Distinction between longitudinal and transverse mesons. Phys. Rev., **69**, No. 10, 843-844 (1941).

LAUFER, M. K., AND L. W. FOSKETT. Daytime photoelectric measurement of cloud heights. J. Res. Bur. Stan., **26**, No. 4, 331-340 (1941).

MINTROP, L. Karl Haussmann zum Gedächtnis. Mitt. Markscheidew., **51**, Heft 1, 1-23 (1940).

MASSACHUSETTS INSTITUTE OF TECHNOLOGY. Studies in terrestrial radioactivity, earth heat, and geologic age measurements from the Physics and Geology Departments of the Massachusetts Institute of Technology. Bull. Geol. Soc. Amer., **52**, 459-600 (1941). [Contents: Radioactivity of rocks, by R. D. Evans and C. Goodman; Age measurements by radioactivity, by C. Goodman and R. D. Evans; Helium retention in common rock minerals, by P. M. Hurley and C. Goodman; Cooling of the Earth, by L. B. Slichter.]

MOUNT WILSON OBSERVATORY. Summary of Mount Wilson magnetic observations of sunspots for January to April, 1941. Pub. Astr. Soc. Pacific, **53**, 132-134, 194-196 (1941).

NATIONAL BUREAU OF STANDARDS. The ionosphere and radio transmission, March, 1941, with predictions for June, 1941. Proc. Inst. Radio Eng., **29**, No. 3, 136-137 (1941).

High-frequency radio transmission conditions, April, 1941, with predictions for July, 1941. Proc. Inst. Radio Eng., **29**, No. 4, 214-215 (1941).

High-frequency radio transmission conditions, May, 1941, with predictions for August, 1941. Proc. Inst. Radio Eng., **29**, No. 6, 349-350 (1941).

Critical frequencies and virtual heights of the ionosphere, observed by the National Bureau of Standards at Washington, D. C., January to March, 1941. Terr. Mag., **46**, No. 2, 246-248 (1941).

NICHOLSON, S. B., AND E. S. MULDERS. Solar and magnetic data, January to March, 1941, Mount Wilson Observatory. Terr. Mag., **46**, No. 2, 252-254 (1941).

PANETH, F. A., AND E. GLÜCKAUF. Measurement of atmospheric ozone by a quick electromagnetic method. Nature, **147**, 614-615 (May 17, 1941).

PARKINSON, W. C. The ionosphere at Watheroo, Western Australia, October, 1940, to March, 1941. Terr. Mag., **46**, No. 2, 223-229 (1941).

VREELAND, F. K. Terrestrial effects of solar activity. Pub. Astr. Soc. Pacific, **53**, No. 312, 98-101 (1941).

WELLS, H. W. Ionospheric recordings during magnetic storm of March 1, 1941. Terr. Mag., **46**, No. 2, 245-246 (1941).

WELLS, H. W., P. G. LEDIG, R. C. COILE, AND M. W. JONES. The ionosphere at Huancayo, Peru, October, 1940, to March, 1941. Terr. Mag., **46**, No. 2, 231-237 (1941).

WRIGLEY, W. Effect of compass location in aircraft on dynamic errors. J. Aeron. Sci., **8**, No. 9, 365-367 (1941).

ZELENY, J. Some observations on electrical discharges from pointed conductors. J. Frank, Inst., **232**, 23-37 (1941).

NOTICE

Some of the early numbers of the Journal *Terrestrial Magnetism and Atmospheric Electricity*, in response to numerous demands, have been reprinted. A few complete unbound sets of Volume I to XLV, therefore, can now be supplied at $140.50 each, postpaid.

Unbound volumes can be furnished at the following postpaid prices each: I to III, $4.00; IV to XXV, $3.00; XXVI to XLV, $3.50.

Single numbers, when possible to furnish without breaking a set, can be supplied at the following postpaid prices each: I to III, $1.50; IV to XLV, $1.00.

Orders should be sent to the Johns Hopkins Press, Baltimore, Maryland.